POLITECNICO DI TORINO

Department of Management and Production Engineering

Master Degree Thesis in Engineering and Management

Discrete Event Simulation of a production line of a tire industry

Supervisor
Prof. GIULIA BRUNO

Candidate
KHALED MOHAMMAD

Academic Year 2023-2024

Abstract

This thesis delves into optimizing tire manufacturing processes through discrete event simulation using FlexSim. The dynamic model simulates production flow, identifies efficient transporter pathways, determines optimal transporter numbers, assesses overall equipment effectiveness (OEE), and optimizes work-in-progress (WIP) between semi-finishing and building stages. Utilizing FlexSim, the research systematically represents the tire manufacturing process, considering factors like production line layout, machine capacities, and transportation logistics.

Results affirm the need for 6 forklift transporters from the warehouse to the semi-finishing area and 1 transporter for delivering final products to the building area, increasing production by about 9 tires daily with a Bi-directional flow. Determinations were made for the Minimum WIP Required and the number of bobbins needed for each material, impacting intermediate queues. Increased handling equipment showed an exponential relation to green tire production, with diminishing returns beyond a certain quantity. Figures indicated a direct proportional relationship between bobbin capacity and green tire production.

Findings contribute not only to tire manufacturing but also offer a valuable methodology for production optimization across industries. Recommendations include optimal transporter routes, appropriate transporter numbers, and OEE metrics for enhancing production efficiency. The study underscores the significance of simulation tools in decision-making processes for manufacturing and production optimization.

Acknowledgements

At the culmination of this academic odyssey, I find myself humbled by the network of support that has illuminated my path. To each and every individual who has played a role, I extend my deepest gratitude.

To my cherished family and my fiancee Dayana Ibrahim, your unwavering belief in my potential has been the cornerstone of this journey. Your encouragement, love, and understanding have fortified me through every twist and turn.

I am profoundly thankful for the guidance and mentorship provided by my managers, Forcella Davide and Lodi Bruno. Your wisdom and expertise have been the lighthouse in this endeavor, steering me through challenges and towards triumphs.

To my academic supervisor, Giulia Bruno, I am indebted for your invaluable insights and scholarly guidance. Your commitment to academic excellence has been a guiding force.

A special note of appreciation goes to my colleague at Prometeon Tyre Group, Syed Moosa Kaleemullah. Our collaboration was instrumental in the success of this project, and your dedication to our shared goals was a constant source of motivation.

To my cousin Ahmad Mohammad, your intellectual curiosity and insightful discussions added depth to my research. Your support was a beacon of encouragement.

The Smart Manufacturing team at Prometeon Tyre Group has been more than colleagues; you have been a source of inspiration and a testament to what can be achieved through collective effort. Our shared pursuit of excellence has been a privilege to witness and be a part of.

Finally, to all those who contributed, whether directly or indirectly, your impact has been deeply felt and is greatly appreciated. This thesis is the product of the collective efforts of a remarkable community.

As I reflect on this journey, I am reminded that it is through the support and encouragement of individuals like you that progress is made possible. Thank you from the depths of my heart.

Contents

List of Figures

Chapter 1

Introduction

1.1 Tyre Industry

Few sectors are as important and widespread around the world as the tyre production field. Tires are the part of a car that touches the road. They are a careful balance of engineering accuracy, material science, and safety. They support the weight, cushion shocks, and make sure there is grip, all while dealing with a wide range of weather conditions. The tyre business is an important part of the car environment because it is always coming up with new ideas and improving performance [1].

1.2 About Company

Going deeply into the types of tires, we see that heavy truck tires are one of the most important sectors of the tyre business, and Prometeon Tyre Group is the top five company overall in the world, which manufactures and sells tires, especially for industry, transport of goods and passengers, and AGRO and OTR applications. Recently, it has included more than 8000 employees and 100 research centers; it also has three crucial research and development centers [2].Officially established in 2017 as a spin-off from the industrial division of PIRELLI Tyre, Prometeon starts its path by producing and selling PIRELLI-branded tires.

Prometeon Tyre Group owned four factories around the world, in Turkey, Egypt, and Brazil, which justifies its large percentage of the market share, and since Prometeon Tyre Group is a leader in the tyre production business when it comes to new ideas and planning a head. Prometeon is always looking for ways to improve its image around the world because it is dedicated to changing the future of mobility. As a big step forward, the company now plans to build a state-of-the-art plant, which will show how dedicated it is to meeting the changing needs of the car industry. This big project not only shows that Prometeon is always trying to be the best, but it also makes the company even more of a leader in the tyre business. With this new addition, Prometeon will not only be able to make more, but it will also further solidify its image around the world as a leader in innovation and forward-thinking. This strategic move starts a new era for Prometeon

Tyre Group, one that is characterised by a strong determination to shape the future of tyre production and change the way we move [2].

1.3 Objectives

To ensure every facet of this new venture aligns seamlessly with their visionary goals, Prometeon invests substantial efforts in rigorous testing along the production line, employing dynamic 3D simulations. This meticulous process aims to optimize key performance indicators and refine logistics, meticulously testing methods that maximize production while minimizing costs.

The scoop of this thesis is to make the automation analysis for the new factory, which will be built by Prometeon Tire Group, so I will make the 3D model for the factory (see Fig.4.29 and Fig.4.30), then by using simulations, I can approve the industrial engineering results, and then I proceed in order to determine the number of transporters needed to supply the machines and to deliver their outputs to other destinations, as well as the optimal way that they must follow in terms of time, velocity, and priorities of the machine requirements. This study will also give the number of pieces of handling equipment required, which will be rotating in a loop among the queues of the machines. I will also determine the maximum capacity of the intermediate queues (WIP), finally, the OEE of the machines as well as the saturation of the transporters.

Chapter 2

Literature Review

2.1 Discrete Event Simulation

Discrete Event Simulation (DES) is a way to model systems where events happen at specific times and are clearly outlined. In DES, time moves in defined steps, which are often called time bits or units. Only at these set event times does the state of the system change, and the game moves on to the next event. This method works especially well for systems that move based on events Fig.2.1, like production lines, traffic systems, computer networks, and queuing systems. DES is the best choice when discrete actions have a big effect on how the system behaves because it offers a strong framework for recording complex relationships among discrete events [3].

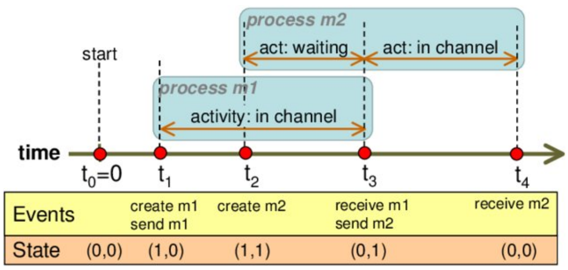


Figure 2.1. Discrete-event simulation concepts

Continuous Simulation (CS), on the other hand, is used for systems that are described by mathematical models that go on forever and where changes happen slowly over time. It is thought of as a continuous variable, and the state of the system changes all the time based on these mathematical models, which are usually shown by differential equations [4] example: Fig.2.2 The game is not driven by clear events like DES is. CS can be used to describe things like the flow of fluids and electricity, as well as biological and economic systems. For accurate modelling of systems whose behaviour is best described by smooth, continuous shifts over time, it works best when numbers change all the time [5]. Discrete Event Simulation can be summed up in the following parts:

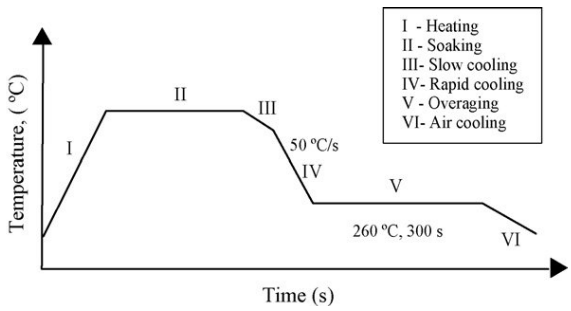


Figure 2.2. Schematic diagram of the continuous annealing process.

- **Definition**

Discrete event simulation is a way to use computers to model how a system works by showing a series of events that happen at different times. These events change the system's state and are dealt with in separate time steps.

- **Components**

Entities are things, people, or parts of the system that can move around. They can be real things, like goods on an assembly line, or ideas, like users in a service system. Events are things that happen and change the state of the system. Events can be entries, exits, breaks, or anything else that is important. Resources are things that are used to carry out processes or jobs. They could be computers, servers, or anything else that provides a service. In queuing systems, things wait in line for resources or processes to become available.

- **Modeling process**

1. Problem Definition: Make it clear what the system being studied is, what it does, and what its goals are.
2. Conceptual Model: Make a rough sketch of the system by listing its main parts, tools, and how they work together. The rules and behaviours that control how things move through the system and how events are handled must be specified.
3. Collecting and Validating Data: Get the right data to set up the model's parameters and make sure it's correct and accurate.
4. Implementation: Use specialised simulation tools or computer languages to turn the mental model into a simulation program.
5. Checking and Validation: Make sure the simulation is a good representation of the real system by contrasting model results with real-world findings. [6]

- **Applications**

Manufacturing and Production: Making the best use of schedules, resources, and production lines. Transportation and Logistics: Looking at how traffic moves, managing the supply chain, and setting up transport networks. Health care: looking into how patients move through hospitals, how resources are used, and how they work. Reviewing investment plans, figuring out how much risk there is, and finding the best ways to run a business are all part of finance and operations. Telecommunications and Networks: Looking at how well networks work, how to handle traffic, and how to provide services [6].

- **Pros and cons**

Realistic Representation: DES models events and their effects over time to show how systems change over time. Experiential learning lets you try out different situations without changing how things work in the real world. Complex System Analysis: DES can work with complicated systems that have many parts that interact with each other and random elements.

- **Limitations**

Sensitivity to Inputs: The results of a model can depend a lot on how good and correct the data that is given is. Resource-heavy: It can be hard to build and run complex DES models on a computer. Assumption Dependency: The correctness of the outcomes relies on the reliability of the assumptions that were used to create the model [6].

- **Conclusion**

Discrete Event Simulation is a flexible and widely used method for comprehending and improving complicated systems in many fields. DES gives us useful information and ways to improve system performance and make better decisions by showing events and processes in great depth and over time.

2.2 FlexSim Environment

Because it takes a whole new approach to simulation modelling and has a brand-new simulation engine that was created and coded over the last year, Flexsim is not like most simulators on the market today. A strong simulation application generator is at the heart of Flexsim. It lets users make totally new simulation applications with custom GUIs, object libraries, and menu layouts for any niche market; consider Fig.2.3. After simulation development projects are finished, they are turned into simulation apps that the creator sells and distributes as a brand-new app, similar to how simulation software is sold today [7]. In this way, Flexsim is not a typical simulation software package. Instead, it is a full-development environment that comes with strong development tools for making simulation software programs that are truly object-oriented, with inheritance for classes and class instances. Each app has both 2D and 3D virtual reality graphics fully built in. All 3D animation graphics are shown in real time using the advanced Flexsim virtual reality graphics engine that comes with every compiled simulation application. The Flexsim graphics engine was created to make simulation animation more realistic and has the same high-quality graphics as video games. Any illustration used in Flexsim is a common object from the modeling world, like a 3D DXF, WRL, or STL file. The C++ engine and Flex-Script, which is a C++ function package, are used to build Flexsim. Because of this, all C++ tools and methods can be used to make applications. Because of this one-of-a-kind method, Flexsim simulation programs are very adaptable and have an easy-to-use setting for building models. You can combine third-party apps like Expert Fit, Opt Quest, and VISIO into the app to give modelers who are making computer models more options and make it easier for them to use. Any ODBC database (like Oracle or Access), any data format (like text, Excel, or Word files), and almost any hardware device that can connect to a computer can be linked to Flexsim. Consider Fig.2.4 [8].

Flexsim's graphics engine, known as Flexsim, is a cutting-edge virtual reality engine that renders 3D animation graphics in real-time. This engine was meticulously designed to offer a level of realism comparable to that found in video games. Consequently, simulations in Flexsim provide an immersive visual experience that enhances the understanding of complex systems [9].

The incorporation of common 3D file formats, such as DXF, WRL, and STL, underscores Flexsim's commitment to accessibility and compatibility. By seamlessly integrating these industry-standard formats, Flexsim allows users to easily import and work with a wide range of 3D models. This empowers modelers to create simulations that closely mirror real-world environments and systems.

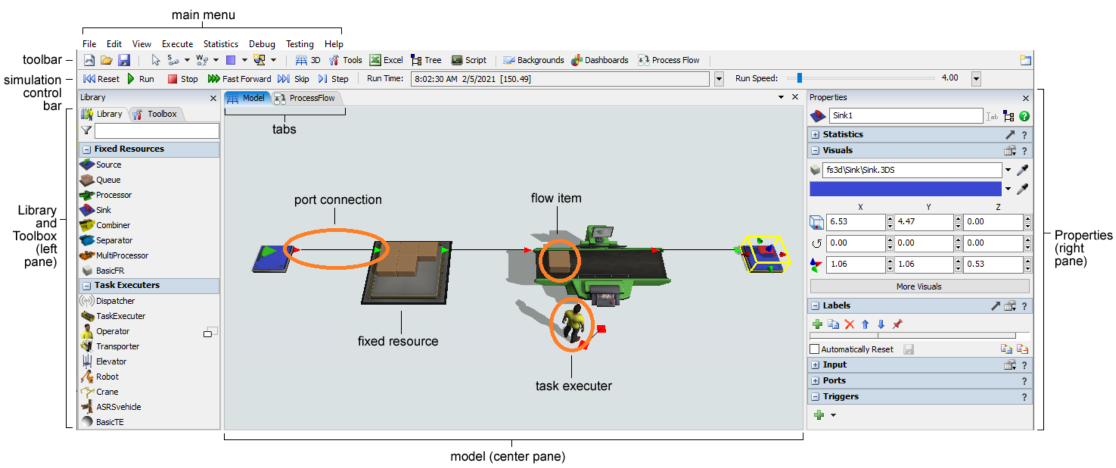


Figure 2.3. Main features in Flexsim

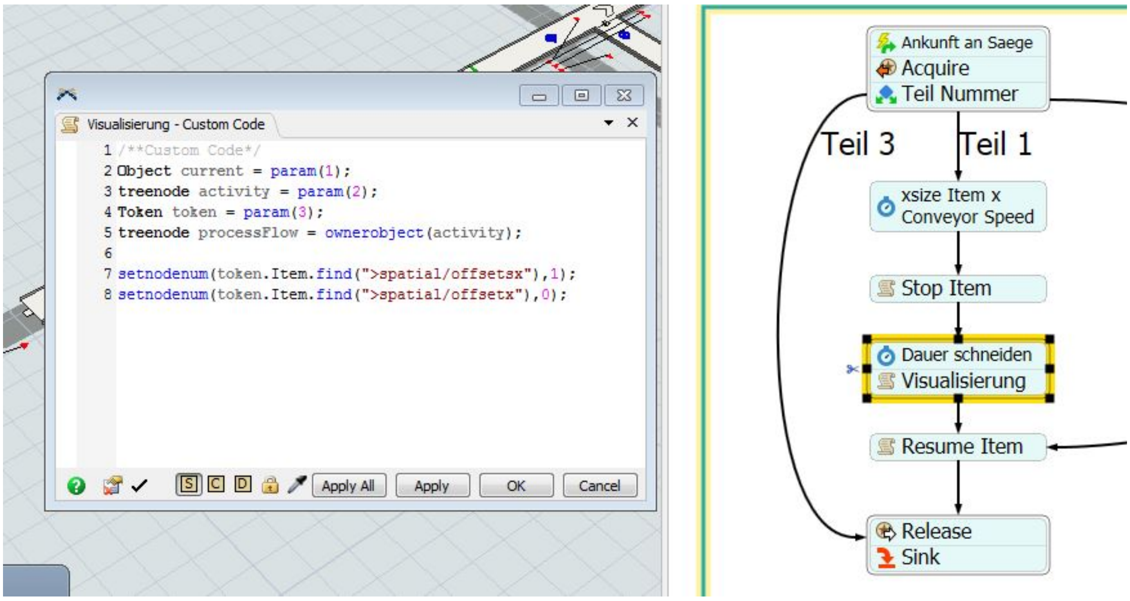


Figure 2.4. Custom code

2.3 Optimizing Production Line

1. **Cycle Time Optimization in Flexsim**

   Through the creative use of Flexsim, "Cycle Time Optimization in Flexsim" starts a full journey into the world of improving production processes. This high-tech modelling tool is a technological wonder. It provides a lively setting for carefully modelling and analysing complex production systems.

   Flexsim can do more than just show how something works; it can also let businesses explore their production lines physically. The main idea behind this research is cycle time optimisation, which is a key part of the quest for business success.

   Looking closely at the details of this process in this piece opens up a world of chances to make things run more smoothly and get more done [10].Where you can control the cycle time considering Fig.2.5, Fig.2.7, and Fig.2.6.

   Flexsim's complex design hides a wealth of tools, each brimming with unique factors and features made to handle the many challenges of cycle time optimization. Users of Flexsim have access to a huge range of tools that can be used to change everything from machine speeds to setup times and resource allocation. What makes Flexsim unique is that it can do dynamic modeling, which lets you simulate different situations in real time. This dynamic method goes beyond rigid images and makes it easy to try new things and come up with new ideas. This piece goes above and

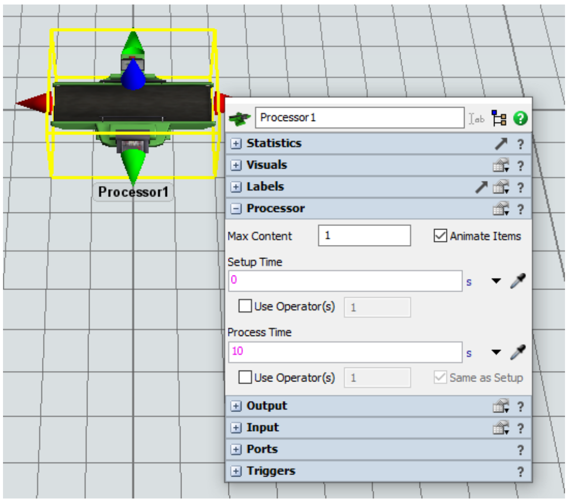


Figure 2.5. Double click on the processor

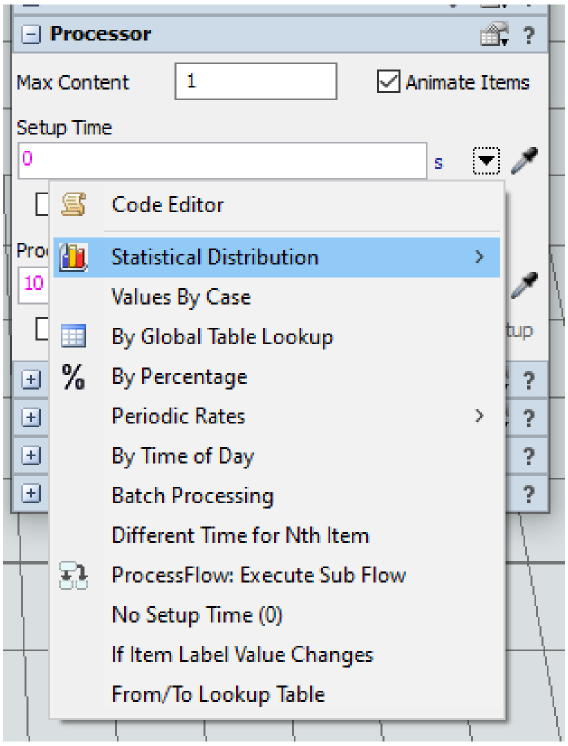


Figure 2.6. Choose the suitable distribution

beyond by using vivid case studies and examples from real life to show how these ideas work. These real-life examples are both inspiring and clear examples of how Flexsim's expertise in cycle time optimisation leads to real benefits like increased

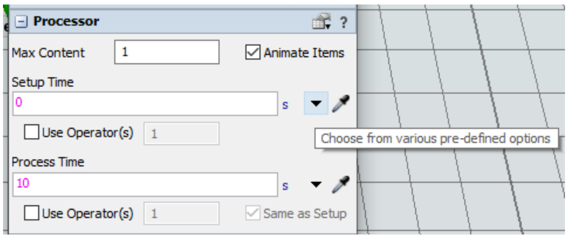


Figure 2.7. Choose the suitable setup time and process time

production capacity, shorter wait times, and better resource management strategies [10].

In addition to the useful examples, the piece is also a great way to find your way around the complicated world of getting the most out of Flexsim. It gives you bits of knowledge in the form of best practices and stresses how important it is to carefully set up and choose parameters. "Maximizing Efficiency: Cycle Time Optimization in Flexsim" is more than just a study; it opens the door to a world of unused production process possibilities. Because it gives companies useful information and deep insights, it helps them use all of Flexsim's modeling power, which opens the door to a future of unmatched efficiency and output [10].

Flexsim's strong modeling tools, on the other hand, let us look at the changing side of cycle time optimisation. Instead of using rigid methods, Flexsim lets users change cycle times flexibly in real time, which is very important for current production settings, consider Fig.2.8. Businesses can get very good at what they do by modeling situations with different processing speeds and setup times. The piece stresses how important it is to make sure that cycle times are in sync with changing market conditions and output needs. Practical strategies are explained that show how Flexsim's dynamic modeling lets companies change their production processes on the fly, making them more flexible and efficient [11].

At last This piece focuses on the strategies and methods in Flexsim that help businesses reach their highest level of operational efficiency. It does this by carefully optimizing cycle times. This shows how important it is to carefully adjust machine speeds, cut down on setup times, and use resources wisely. Through careful testing and research in the Flexsim system, users can find the cycle times that work best for their unique production processes. The piece talks about the benefits of this level of accuracy, such as higher production rates and shorter wait times. If businesses fine-tune these important factors, they can start on the path to operational success, which will give them an edge in the market [12].

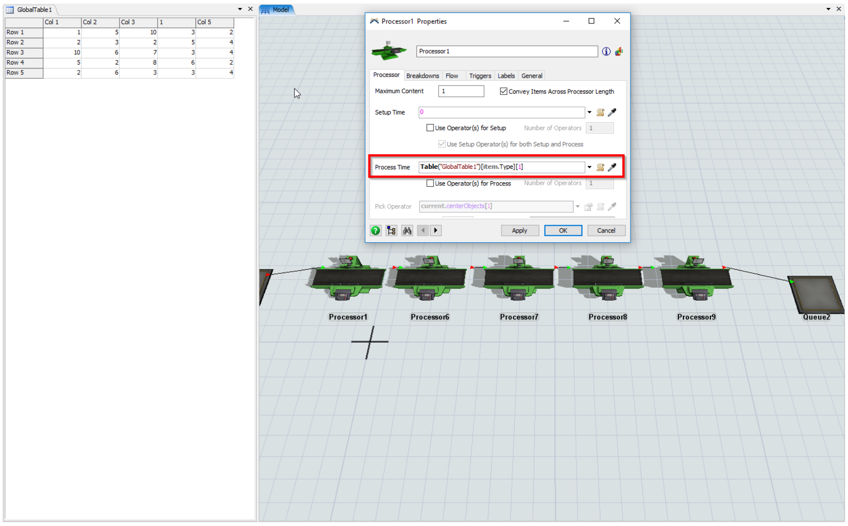


Figure 2.8.   Parameterization of cycle time

2. **Process Flow Analysis and Simulation**

According to [13], the capabilities of dynamic simulation that Flexsim offers provide enterprises with the ability to go on a road towards operational excellence via the examination of process flow. Consider Fig.2.9. This essay explores the revolutionary potential of Flexsim, which provides a virtual platform on which the complexities of manufacturing lines may be modeled in minute detail. Flexsim enables users to get a comprehensive grasp of the flow of materials and products by placing them in a virtual simulation of the activities they are responsible for. This skill has proven to be quite useful in locating bottlenecks, which are obstacles that prevent efficiency from being achieved; consider Fig. 2.10. Users are able to determine the most efficient route and distribute resources effectively if they have a keen eye. The end result is the establishment of a manufacturing line that is streamlined and effective and that is prepared to fulfill the requirements of a dynamic market. Moreover Flexsim shines as a model of forward-thinking innovation within the context of production optimisation, and there are many options provided by Flexsim for optimising the flow of production. It provides customers with a toolbox that has a variety of functions and enables them to alter machine speeds, optimise setup times, and precisely allocate resources. The manufacturing capabilities are increased, and the lead times are decreased, as a result of the strategic calibration of these factors. In its most fundamental sense, Flexsim acts as a catalyst for operational excellence, giving organisations the ability to obtain a competitive advantage in a market that is always shifting.

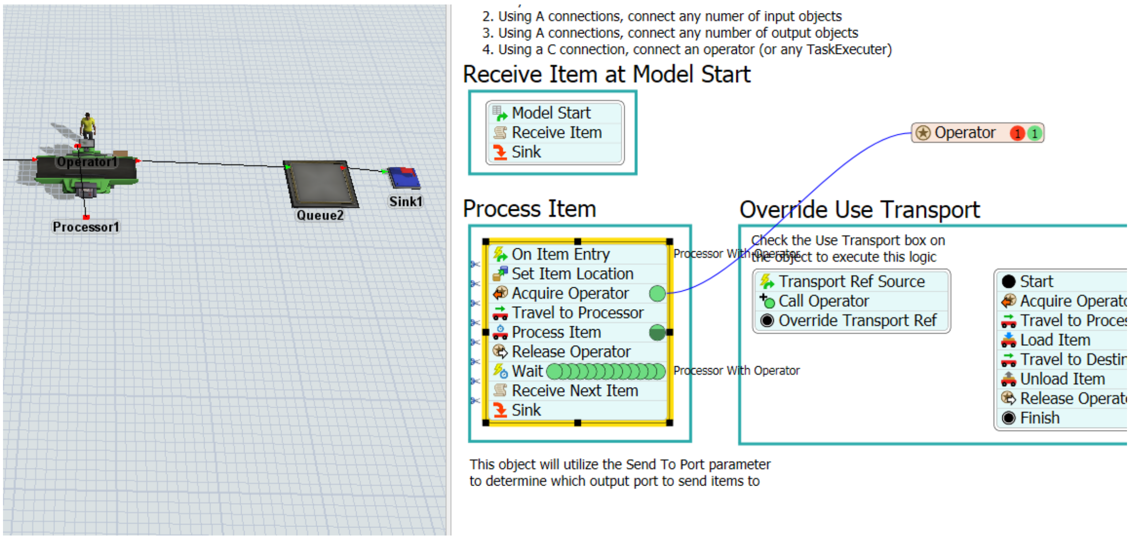


Figure 2.9. Running the process flow

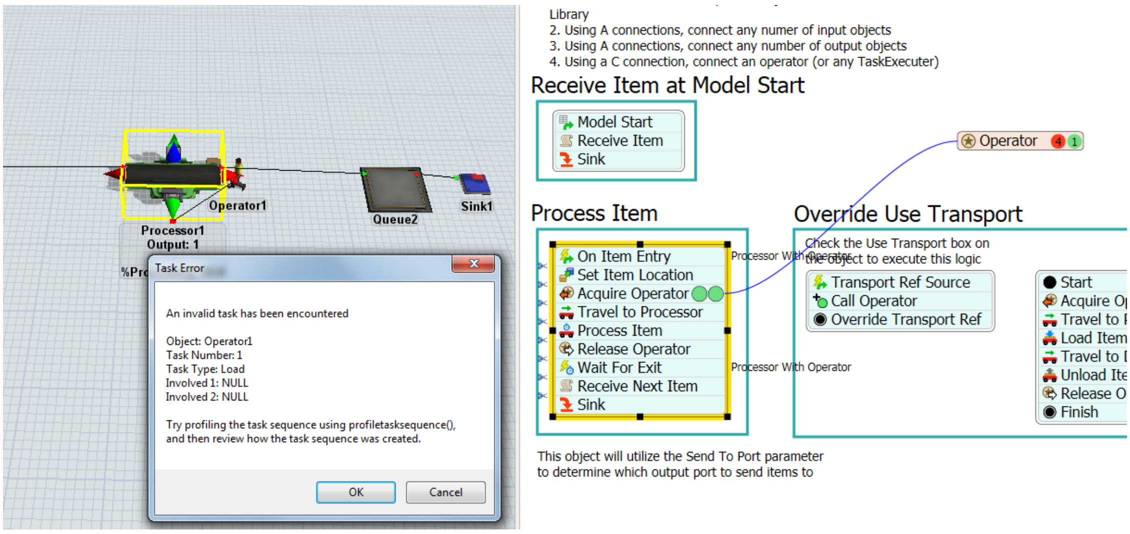


Figure 2.10. Follow and fix the given errors

In the context of improving operational efficiency, having the capacity to both see and analyse the flow of operations is a game-changing skill. Flexsim's strengths include providing users with the ability to accomplish just that. A bird's-eye perspective of the flow of materials and products through a production line is made available by Flexsim, which does this by offering a dynamic simulation platform. This vantage point is quite helpful in determining which aspects of the system need to be improved and enhanced. The platform makes it possible to perform strategic re-configurations of routes and allocations of resources, ensuring a continuous flow of activity. Businesses are able to get a clear visual view into the core of their operations by using Flexsim, which paves the way for a change towards increased efficiency [14].

When it comes to achieving operational excellence, Flexsim is a reliable partner to have on your side. It does this by providing capabilities for dynamic simulation, which enables firms to delve deeply into the complexities of manufacturing processes. This virtual platform offers an environment in which the modelling and analysis of every facet of the manufacturing process may be carried out in minute detail. As a consequence, users are provided with a thorough awareness of the flow of both materials and products, which enables them to discover bottlenecks and prudently assign resources. This, in turn, leads to the establishment of a manufacturing line that is both smooth and efficient and is ready to fulfil the needs of an ever-changing market.

In addition to comprehension, Flexsim provides a toolbox for the improvement of models. Users are able to precisely adjust machine speeds and setup times, as well as allocate and distribute resources. This strategic adjustment results in increased production capabilities and decreased lead times. Therefore, Flexsim acts as a catalyst for operational excellence, giving organisations the ability to achieve a competitive advantage in a market that is always changing.

When it comes to optimising operational efficiency, visualisation is of the utmost importance. Flexsim is a dynamic simulation platform that gives users a bird's-eye perspective of the flow of materials and products through a manufacturing line. This vantage point is quite helpful in determining which aspects of the system need to be improved and enhanced. The platform makes it possible to perform strategic re-configurations of routes and allocations of resources, ensuring a continuous flow of activity. Businesses are able to get a clear visual view into the core of their operations by using Flexsim, which paves the way for a change towards increased efficiency.

3. **Material Handling and Transportation Modeling**

   Flexsim has established itself as an industry leader in terms of effective logistics and the management of materials. It is particularly adept at modelling and simulating complex material handling systems, which is the source of its competitive advantage. The dynamic simulation environment provided by Flexsim gives users the ability to reproduce the delicate movement of materials using a variety of transport techniques. This capability was previously unavailable. These include automated guided vehicles (AGVs); consider Fig. 2.11, often known as conveyors and forklifts, and they are all connected together without any hiccups inside the Flexsim platform. This all-encompassing modelling capacity serves as the foundation for maximising the efficiency of the complex logistics involved in material movement [15].

The skill of determining the most effective route to take is essential to the success of this endeavour. Flexsim provides customers with a toolbox that enables them to determine which pathways are the most effective for the transportation of stuff. By meticulously planning these routes, companies can substantially cut down on the amount of time it takes for products to be transported from one location to another, ensuring that the items reach exactly when and where they are required to do so, consider Fig.2.13. In addition, the platform makes it easier to meticulously plan pickups, which helps to ensure a streamlined and coordinated movement of materials throughout the production environment. The final result is an atmosphere in which idle time is kept to a minimum while productivity is increased, culminating in a logistical framework that functions with the efficiency of a well-oiled machine [16].

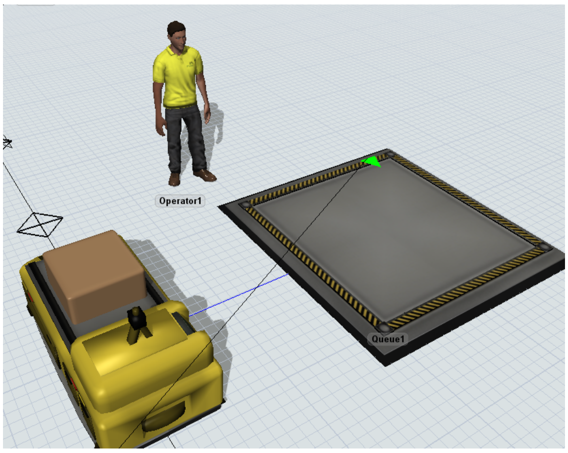


Figure 2.11. AVG-Operator-Queue

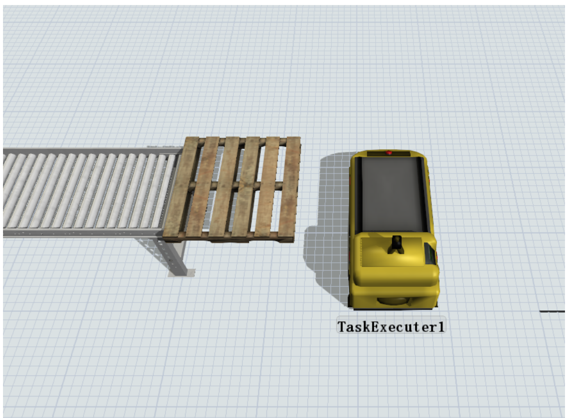


Figure 2.12. AGV waiting for Pallet

The art of route optimisation is at the heart of this paradigm; it is a strategic cornerstone that can be realised more easily thanks to Flexsim's improved capabilities. Users are able to trace the most effective routes for materials, redefining transit times and assuring a flawless meeting at their intended destinations by using accuracy and foresight in their planning. The result is a significant reduction in downtime, an increase in productivity, and a better matching of available resources to the requirements of daily operations. This accuracy extends to the strategic pickup schedules, which further enhance the ballet-like movement of materials [17]. The end result is a framework for logistics that functions with the same level of accuracy and effectiveness as a ballet,Fig.2.12 that has been painstakingly choreographed.
Flexsim genuinely shines in this ever-changing environment of material handling, offering itself as a vital ally for firms that want to master the art of material flow optimisation. It models and mimics every detailed step of material movement, combining an extensive variety of transportation techniques in a seamless manner, which is how its flexibility becomes apparent. Forklifts are able to negotiate the manufacturing floor with dexterity and accuracy, while conveyors serve as the structural backbone, ensuring that materials are moved in a consistent manner. Automated guided vehicles, often known as AGVs, are quickly becoming the autonomous workhorses of the modern day, moving things in a systematic manner to the sites to which they are assigned. When using Flexsim, every aspect of the material handling process is placed in its appropriate location on a virtual canvas, where it may then be optimized [18]. The spotlight is now on path optimisation, the essential strategy that underpins Flexsim's design. In this area, users methodically create the paths that materials go down, polishing each path to its utmost potential in the process. The end effect is a considerable decrease in transportation times, which guarantees that products reach exactly when and where they are required. This accuracy is revolutionary, slashing the amount of time spent idling and rocketing total output inside the industrial environment [19]. Additionally, customers are given the ability to design smart pickup plans via the use of Flexsim, which guarantees a constant and effective flow of commodities. Because of Flexsim's sophisticated modelling capabilities, the finished product is a process of material handling that is both precise and effective.

A platform that specialises in modelling and optimising material flow is one that Flexsim provides. Material handling is a complex dance, and Flexsim orchestrates a symphony of efficiency in that dance. The dynamic simulation environment, in which users may imitate the movement of items via a wide variety of transportation techniques, is the platform's primary point of differentiation and its primary source of value. Flexsim offers a full tool set for modelling and optimising material handling operations [20]. This toolkit includes conveyors, which constitute the backbone of material transportation; nimble forklifts, which traverse the production area with accuracy; and automated guided vehicles (AGVs), which work autonomously.

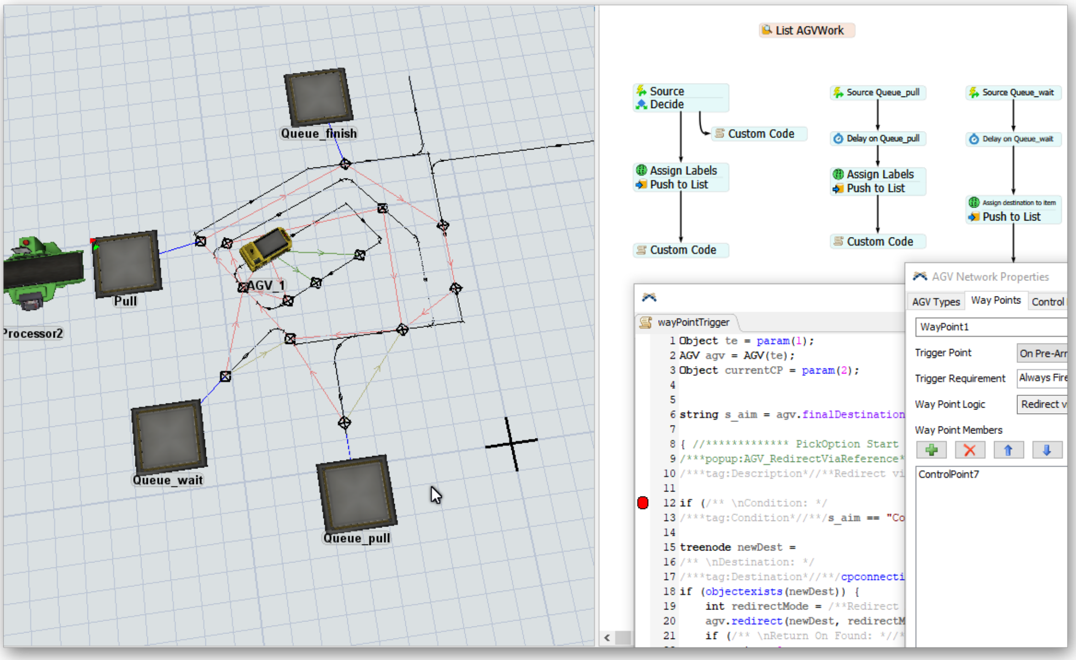


Figure 2.13. AGV parking logic

Path optimisation is the primary tactic in material handling optimisation, and Flexsim offers the required tools for customers so they may properly design and optimise material paths. Businesses have the ability to dramatically cut down on transit times by deliberately choosing these routes, which ensures that supplies get to their destinations in a timely manner. This level of accuracy in the flow of materials has a significant bearing on the reduction of downtime and the enhancement of overall productivity. Additionally, customers are given the ability to design smart pickup plans via the use of Flexsim, which guarantees a constant and effective flow of commodities. Because of this, the process of material handling is smooth, and it is also characterised by accuracy and efficiency. All of this is made possible by the powerful modelling capabilities of Flexsim [20].

4. **Overall Equipment Effectiveness**

The assessment of overall equipment effectiveness (OEE) is one of the most important aspects of Flexsim's contribution to the field of operational excellence since it helps to ensure that production is increased to its fullest potential. With the assistance of this dynamic simulation platform, organisations are able to conduct in-depth analyses of the ways in which their equipment and resources function [21]. Instead of depending on theoretical evaluations, Flexsim provides a virtual environment in which the interaction between availability, performance, and quality can be seen in vivid detail. Because of the immersive nature of this technique, users are able to evaluate the genuine efficacy of their manufacturing equipment in the context of real-world circumstances.

The OEE assessment is based on deconstructing three essential components: availability, performance, and quality. This is when the evaluation really gets down to business. The term "availability" refers to the amount of time during which a piece of manufacturing equipment is really accessible for use. Users have access to a full toolbox inside Flexsim, which allows them to model and simulate the many downtime situations that might take place within a production system [21]. Businesses are able to acquire invaluable insights into possible bottlenecks and inefficiencies in their operations by carefully analysing the times when their resources are unavailable.

In the context of manufacturing, performance refers to how well certain pieces of machinery carry out their functions. The dynamic modelling features of Flexsim enable users to fine-tune machine speeds and process durations, offering a nuanced view of performance indicators. Businesses are able to determine the ideal settings for their equipment by simulating a variety of different situations. This improves the performance of the equipment as a whole [22].

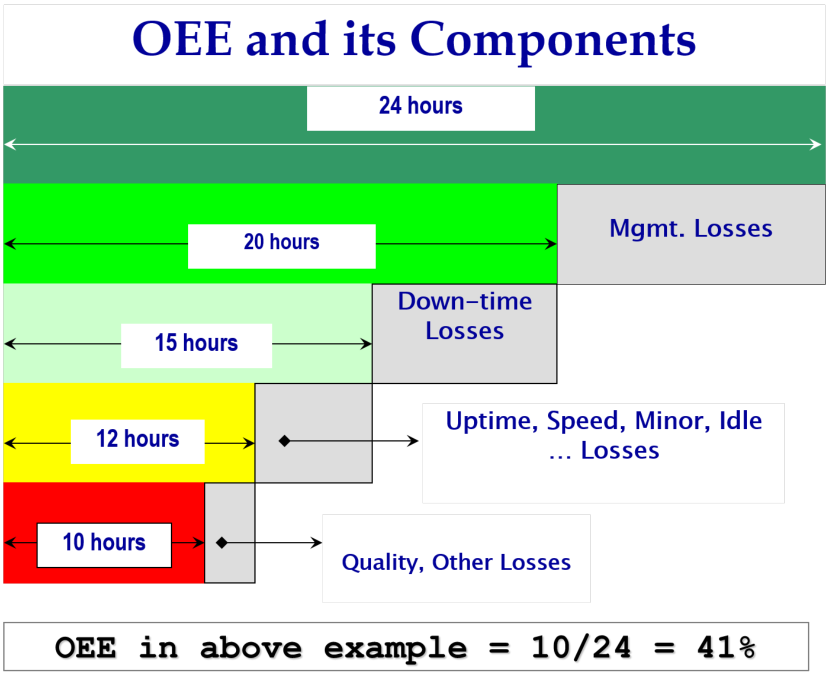


Figure 2.14. OEE components

The OEE model is built on three pillars: the third is quality, which encompasses the accuracy and precision of manufacturing processes. Users are given the ability to mimic quality control methods via the use of Flexsim, which ensures that only items that fulfil the requirements stated are taken into consideration during the evaluation. This specific aspect of OEE assessment is especially important in businesses in which accuracy and compliance are of the utmost importance [23].

The incorporation of all of these components within Flexsim makes it possible to conduct an exhaustive analysis of OEE. In this way, companies may get a comprehensive perspective of the performance of their machinery, moving beyond the realm of theoretical models and into the realm of the operational reality of production. This newly acquired insight paves the way for several opportunities for enhancement and development [24].

Flexsim does not only settle with assessment as part of its mission to achieve excellence in operational performance. It acts as a driving force behind the implementation of methods to improve overall equipment effectiveness. Businesses are in a better position to strategically deploy their resources, fine-tune their maintenance schedules, and make process changes when they have a comprehensive awareness of the operation of their equipment. Users are able to experiment with a variety of tactics thanks to the dynamic modelling capabilities offered by Flexsim. This helps users ensure that the treatments they choose are both successful and sustainable [25].

In essence, Flexsim gives companies the ability to go on a path of continuous development, using OEE assessment as the compass to lead them towards increased productivity. Through the use of this dynamic platform, theoretical estimates of efficiency are converted into concrete, practical findings. Businesses are able to not only monitor their efficiency but also unleash the potential for previously unattainable levels of productivity and operational excellence when they use the power of Flexsim [26].

2.4 Usage of FlexSim in the tyre industry

Flexsim is modelling software that can be used in many different fields, including the tyre production business. In the tyre business, Flexsim is used to model and improve production methods, which gives companies a lot of useful information. Here are some ways that Flexsim is used in the tyre production process:

1. **Optimising the tyre production line**

   Optimizing the tire production line is a very important part of making things in the car business. It involves systematically reviewing and improving all the steps that go into making tires, from the raw materials that are used to the finished product that is sent out. One important part is using new technologies like robots and automatic machines to make things more accurate and efficient Fig.2.15. This speeds up the production process and reduces mistakes made by people, which results in better goods. Implementing lean production concepts, such as Just-In-Time (JIT) inventory management, also helps cut down on unnecessary overstock and waste, which saves money and makes better use of resources. Using data-driven analytic and predictive maintenance together also lets you keep an eye on how your equipment is working in real time, which helps keep it from breaking down and makes maintenance plans more effective [27].

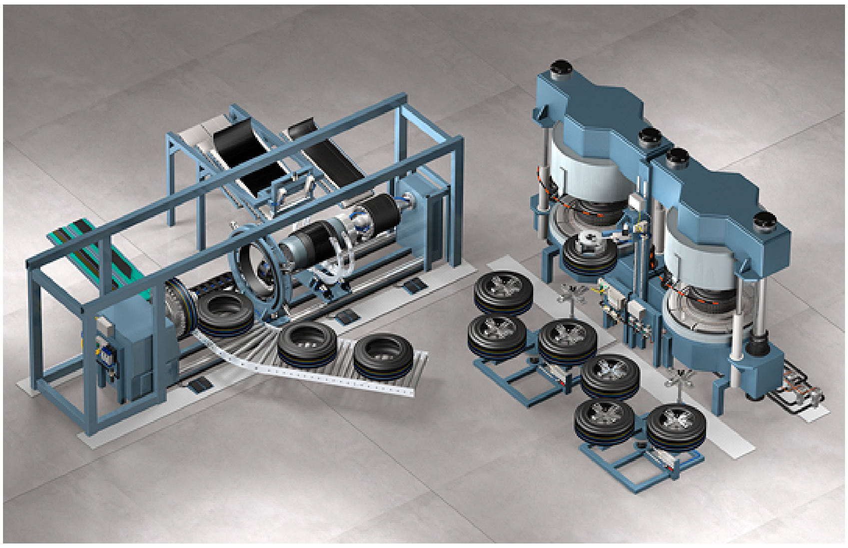


Figure 2.15. Fluid automation solutions

In terms of protecting the environment, improving the tyre production line also means lowering the damage that industrial methods do to the environment. This includes looking into making tires out of eco-friendly materials and starting recycling programs to deal with trash. Using tools and methods that save energy also helps to reduce the amount of resources used and greenhouse gases released during the production process [28]. This not only fits with world goals for sustainability, but it also makes tyre companies look like more socially responsible businesses.

Working together with sellers and other important people is key to optimizing things. Building strong ties with providers of raw materials helps keep the supply chain stable, cuts down on wait times for purchases, and improves the general efficiency of production [29]. Taking a complete method that includes both new technology and bettering processes also encourages a mindset of constant change, which helps the tire production industry stay competitive and make money in the long run.

2. **Inventory Management**

Inventory management is a key part of making tire production lines work better Fig. 2.16. The fact that a tire warehouse used Flexsim to model its inventory management shows how simulation-based methods could be useful (Fig. 2.17). Using this technology gives the warehouse a moving tool to test and study different parts of inventory management, like how tires move around the warehouse, methods for restocking, and the rate at which items are sold and replaced [30].

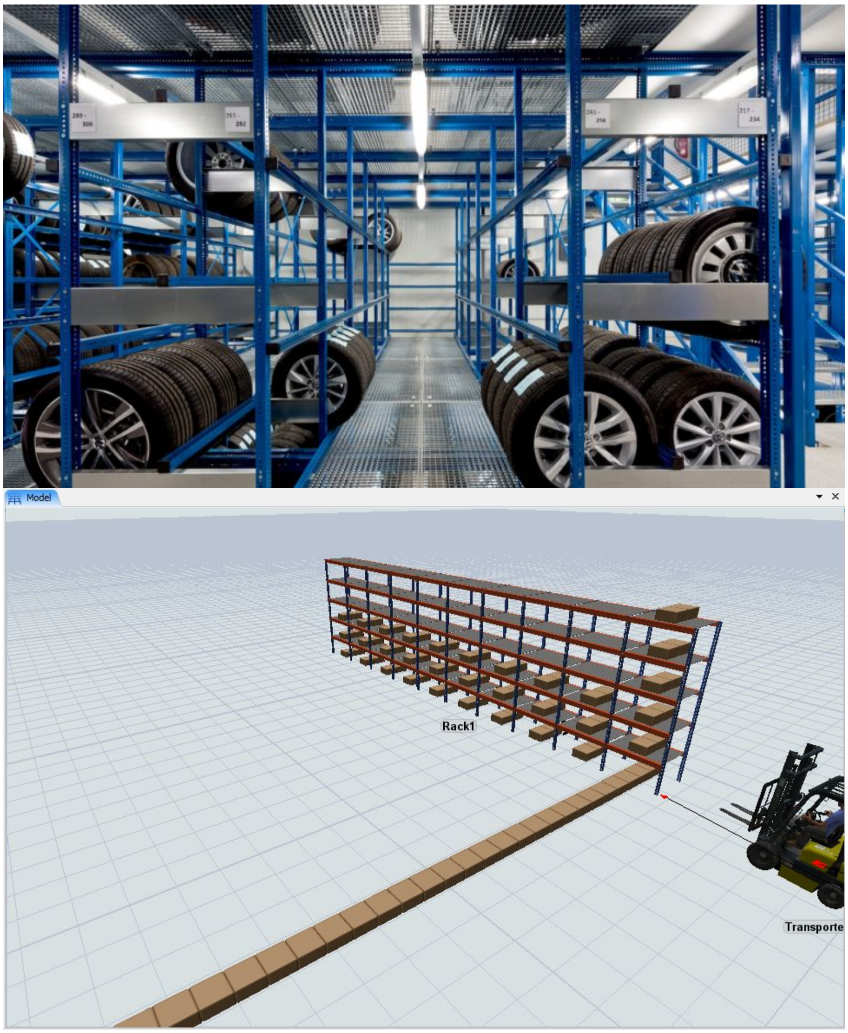


Figure 2.17. Rack representing a storage

This method has a number of benefits. For starters, it lets you fully test out a lot of different options and situations. This means that the warehouse can try out different amounts of stock and prices to carry them to find the best mix. Simulations make it possible to see how these changes will affect things in a controlled setting without stopping real-world activities. This not only cuts down on unnecessary stock, but it also makes sure that the company always has enough stock to meet demand and avoid running out of items [30].

Using Flexsim to keep track of goods also gives the warehouse a useful tool for making decisions based on data. If the building wants to make changes based on real-world data, the modelling program gives them useful information about how different tactics work. This data-driven method is necessary for managing supplies in a way that is both efficient and cost-effective [30].

3. **Quality Control and Assurance**

   When it comes to making tires, Flexsim stands out as a key tool for improving quality control. Utilizing Flexsim's modeling features, makers get a complete picture of how checks, testing processes, and flaw repair methods work together in the production line. This dynamic modeling helps them figure out the best ways to keep quality high, which increases production efficiency and raises the quality of the finished goods [31].

4. **Material Handling and Logistics**

   Flexsim is very helpful for improving material handling processes in the tire distribution field. Utilizing conveyors, trucks, and other handling tools, the software creates complex images of the complex movement of tires. This careful method helps distribution centers figure out the best plans, ways to store items, and rules for handling, which leads to better resource and operating efficiency [32].

5. **Resource Allocation and Scheduling**

   Within tire manufacturing plants, the strategic deployment of resources is paramount for seamless operations. Flexsim serves as a linchpin in this regard, facilitating the optimization of resource allocation encompassing machine scheduling and labor assignments. Through meticulously designed simulations, manufacturers can explore diverse scheduling scenarios, ultimately pinpointing the most efficient utilization of resources. This results in heightened productivity and cost-effectiveness in meeting production targets [33].

Chapter 3

Green Field : Thesis Case Study

3.1 Background

I discussed in the previous case studies the benefit of using Flexsim in order to optimize the KPIs of the production line in general, and now I will go into details, showing our industrial case study of the production line for Prometeon Tyre Group, which is called Green Field Studies because it has not been built yet, and the following study will be considered one of the most basic studies that will help us understand and confirm the whole industrial engineering measurements and KPIs.

As we discussed before, Prometeon has four factories: two in Brazil, one in Turkey, and one in Egypt. So, by including these factories as an industrial case study, we can say that the production of tires involves about 8 steps:

1. **Preparation of raw materials**

   The first step in the process is the production of the raw materials, which include natural rubber, synthetic rubber, fabric, carbon black, sulfur, and other chemical compounds. Natural and synthetic rubber are two types of raw materials.

2. **Compound Mixing**

   To produce the rubber compound, the raw components are combined in the appropriate proportions and then mixed together. After that, the mixture is sent through a number of different machines Fig.3.1 in order to get the necessary uniformity and characteristics.

3. **Component Preparation**

   The tread, the sidewall, the inner liner, the belts, and the beads are all parts that make up the tire. Other components include: Every one of these elements undergoes independent preparation; consider Fig. 3.2.

Figure 3.1. A Banbory

Figure 3.2. Belts Extruder

4. **Building the Tyre**

   The tire is assembled by first mounting a drum and then stacking each of the component parts. There is a certain order in which the inner liner, the body ply, the belts, and the other components are attached.

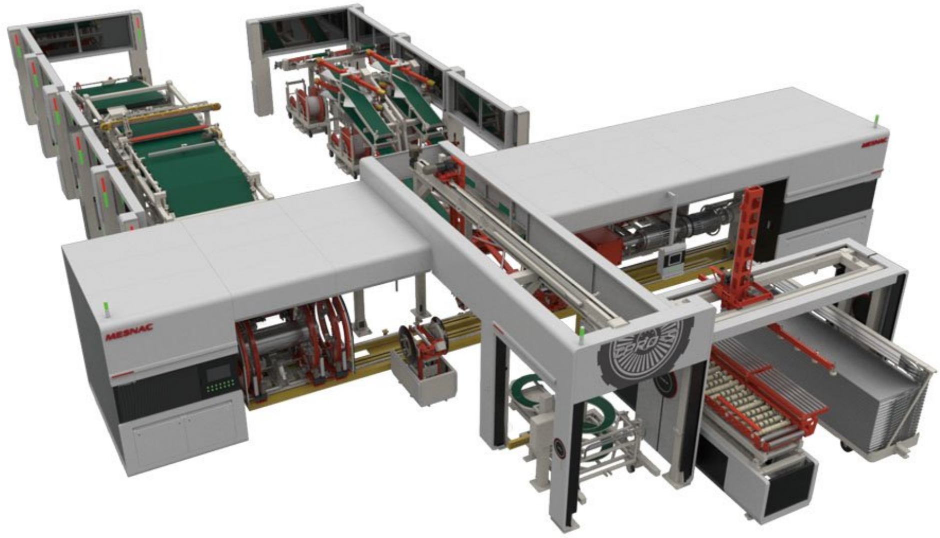


Figure 3.3. MESNAC machine

5. **Curing**

   After placing the green tire, also known as an unvulcanized tire, in a mold, the tire is then heated. Curing, also known as vulcanization, is a process that chemically binds the rubber components, which in turn provides the tyre with its definitive form and the ability to withstand force (see Fig. 3.4).

Figure 3.4. Curing

6. **Inspecting and Testing**

   Each tyre is put through a battery of inspections and testing to guarantee that it satisfies the quality requirements Fig.3.5. This involves tests for consistency, balance, and flaws visible to the naked eye. Fig.3.6

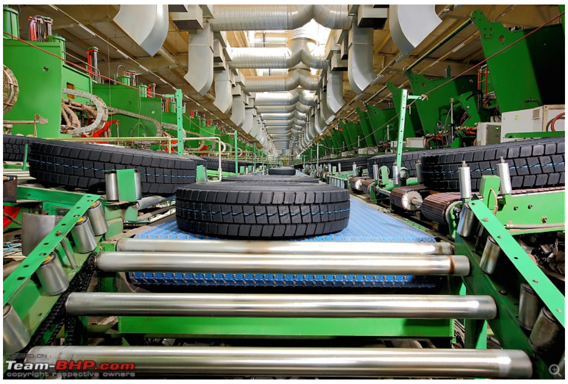


Figure 3.5. The tires being sent for an inspection

7. **Quality control**

   Samples of each batch of tires are put through strict quality control tests to make sure that they meet the standards for both safety and performance.

Figure 3.6. Manual inspection

8. **Packaging and Storage**

   When all of the quality tests have been passed, the tires are next packed and made ready for delivery to either distribution centres or the end users themselves (see Fig. 3.7).

Figure 3.7. Production Warehouse

3.2 Data Collection for the Machines

Collecting data is like creating a map before you go on a journey with your FlexSim project. It's important because it helps you understand where you are, where you want to go, and how to get there. Here's why collecting data is crucial:

1. **Understanding Your Starting Point:** Data collection gives you insights into your current processes and systems. It's like knowing your exact location on a map. You can't plan a journey without knowing where you're starting.

2. **Identifying Problems:** Data reveals any issues or inefficiencies in your current operations. These are like roadblocks on your journey, and you need to know about them to plan around them.

3. **Setting Goals:** You can't plan a trip without a destination in mind. Data helps you set clear objectives for your FlexSim project, defining where you want to go and what you want to achieve.

4. **Optimizing Routes:** Just as you'd choose the best route on a map, data helps you find the most efficient path for your project. It guides you in making informed decisions about how to reach your goals.

5. **Resource Allocation:** The data shows you where you're currently allocating resources. This is essential for deciding where to invest time, money, and effort in your project.

I've described the tire industry's production line in general, but Prometeon Tyre Group is only interested in simulating the first four areas—that is, up until the production of green tires—because AVG will automate the remaining areas, which are outside the project's scope. Since the project's goals include managing the process flow from the warehouse to the finishing area with the fewest possible transporters and verifying the results provided by the industrial team. The first step that should be taken is the collection of the necessary data in order to start building your logic of the material flow from one area to another and to setup the connection between the machines.

The scope of the project is to simulate only the warehouse, semi-finishing, and building area.

I. Warehouse Area

Where the factory received the raw materials from the suppliers in order to feed the banbories mixers and the machines in the semi-finishing area. In this project, I will use the following **main raw materials:**

Service Liner: The service liner, sometimes referred to as the inner liner, is a distinct layer composed of a specialized rubber compound that is situated inside the structure of a tire. The basic purpose of the tire is to establish an impermeable seal, therefore inhibiting the escape of air through its composition. The use of this liner is essential for the maintenance of appropriate tire pressure, a critical factor in ensuring the safety and optimal performance of the vehicle.

Polyethylene: Polyethylene is a polymer that is derived from the repetition of ethylene molecules. Polyvinyl chloride (PVC) is a commonly used thermoplastic material renowned for its notable attributes such as robustness, malleability, and resilience against moisture, chemicals, and physical force. Polyethylene is often used in several parts of the tire business, including as inner liners, sidewalls, and other structural elements, in order to improve their performance attributes (see Fig. 3.9).

Steel Wire Pallets: Steel wire pallets are structural units composed of steel wires arranged in a grid-like arrangement. The use of these pallets serves the purpose of enhancing the internal framework of a tire, hence imparting robustness and steadfastness. The reinforcing materials are deliberately positioned throughout the tire's structure to provide structural integrity and enhance its ability to withstand the various mechanical forces encountered during operation.

Bead wire: The term "bead wire" refers to a particular type of steel wire with exceptional strength and a fine structure that frequently has a brass or bronze coating (see Fig. 3.8). The bead, which is the component of the tire that comes into contact with the wheel rim, is used in tire manufacturing for this purpose. The use of bead wire is essential in maintaining a solid and stable connection between the tire and the rim, hence facilitating appropriate installation and guaranteeing optimal stiffness and flexibility.

Figure 3.8. Bead Wire

Figure 3.9. Polyethylene

II. Semi-Finishing Area

Is the most complicated area because it houses all the machines in charge of creating the final materials that the building machines require, as well as the semi-finishing products that other semi-finishing machines use.

1. **Metallic Calender:**
   The metallic calendar is a mechanical device used within the tire production process for the purpose of molding and refining the constituent elements of the tire. The tire manufacturing process involves the use of many metallic rollers that exert both pressure and heat on the tire material. This method makes it easier to get the

exact sizes, uniformity, and surface properties of tire parts like treads, sidewalls, and inner liners (see Fig. 3.10).

Figure 3.10. Metallic Calender:

Figure 3.11. Data required for Metallic Calender

2. **Textile Calender:**
   The textile calender is an additional machine used in the manufacturing process of tires. In contrast to the metallic calender, the calender in question employs rollers made of textiles to exert pressure and heat on the tire materials. This method makes it easier to get the right thickness and texture for a number of parts, especially those that need a softer touch or a different finish than what metal rollers can provide.

Figure 3.12. Textile Calender

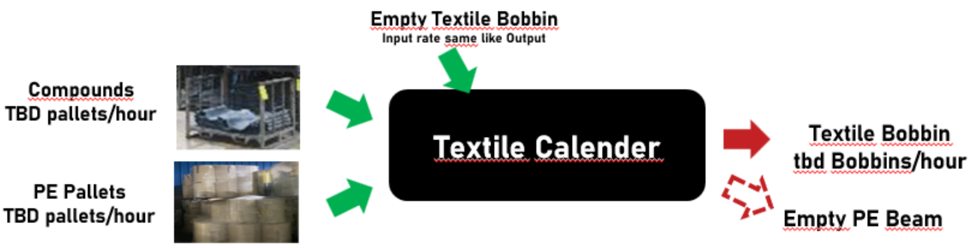


Figure 3.13. Data Required for Textile Calender

3. **Quadrublex Tread Extruder:**
   The quadruplex tread extruder is a device used in the process of extruding rubber compounds, specifically for the purpose of manufacturing tire treads. The machine in question has a high level of complexity, enabling it to generate elaborate tread patterns with a remarkable degree of accuracy. Tread patterns play a crucial role in determining the traction, handling, and many other performance attributes of a tire.

Figure 3.14. Quadrublex Tread Extruder

Figure 3.15. Data Required for Quadrublex

4. **Bead Filler Applicator:**
   The bead filler applicator is a mechanical device used for the purpose of applying filler material to the bead region of a tire. The bead refers to the specific region of the tire that comes into contact with the rim. The use of filler material serves the purpose of establishing an effective seal between the tire and the rim, therefore augmenting both stability and safety.

Figure 3.16. Required Data for Bead Filler Applicators

5. **Duplex Side Wall:**
   The duplex side wall machine is used for the purpose of shaping and refining the sidewall constituents of a tire. The aforementioned factor plays a pivotal role in ascertaining the structural integrity, flexibility, and aesthetic attributes of the tire. The sidewall of a tire serves the purpose of providing structural support and offering a protective barrier.

6. **Duplex Bead Filler:**
   The duplex bead filler is a mechanical device used for the simultaneous application

of filler material to both sides of the bead. The use of this mechanism guarantees a consistent and safe connection between the tire and the rim, hence facilitating appropriate installation and enhancing stability.

7. **Duplex UBF:**
   The Duplex UBF (Ultimate Bonding Function) is a special machine that is made to make the adhesion between different parts of a tire, like the tread and the inner liner, better. The establishment of a robust and dependable connection is crucial to ensuring the longevity and effectiveness of tires.

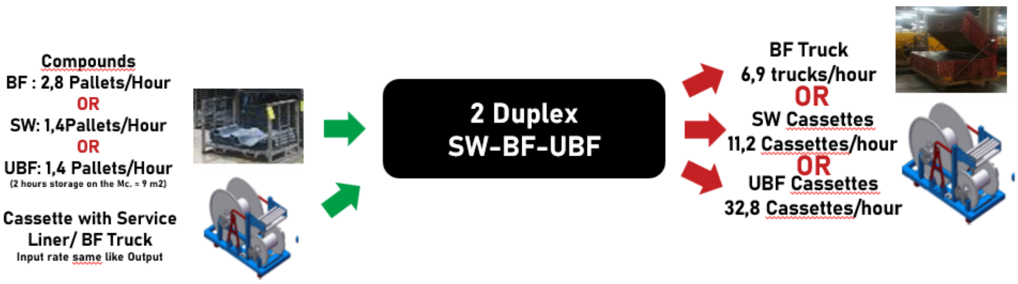


Figure 3.17. Required Data for Duplex SW,BF,and UBF

8. **Monowire Bead:**
   The monowire bead machine is used for the production of a bead wire assembly using a solitary wire. The aforementioned component serves as the tire's bead, offering the essential characteristics of both stiffness and flexibility to ensure a stable attachment to the wheel rim.

Figure 3.18. Required Data for MonoWire Bead

9. **TTM 90-degree:**
   The TTM 90-degree machine is presumably a constituent of a tyre manufacturing

assembly; however, precise details on its use are not immediately accessible given the contextual information supplied.

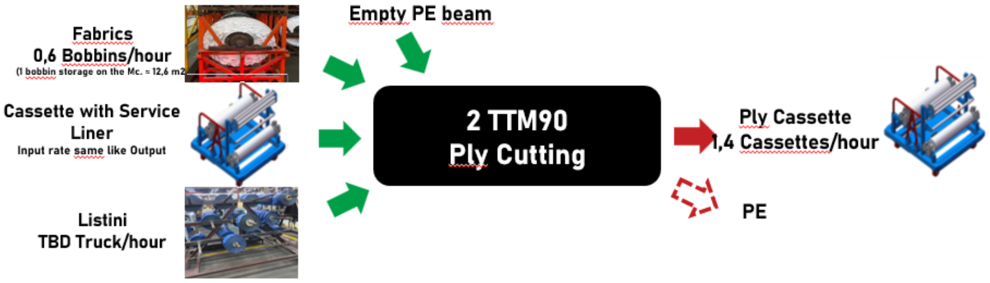


Figure 3.19. Required Data for Ply

10. **1st, 2nd, and 3rd Belts:**
    Within the realm of tire production, the designations of the 1st, 2nd, and 3rd belts pertain to distinct strata of reinforcing materials, often including fabric or steel cords, which are integrated into the tire's overall structure. The use of these belts enhances the tire's structural integrity and enhances its overall performance and longevity. The second and third belts come after the first belt, which is frequently considered the innermost stratum.

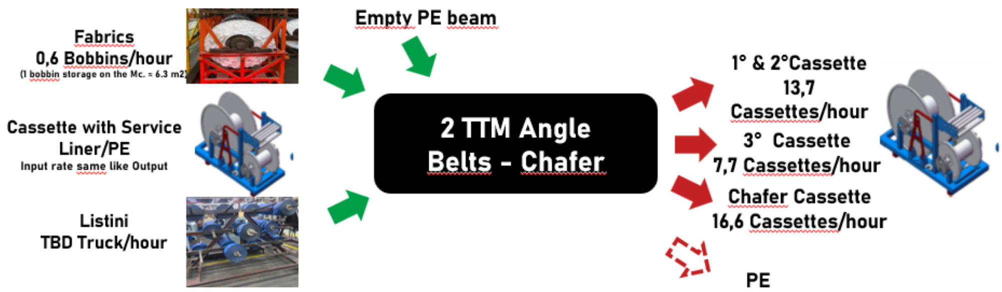


Figure 3.20. Required Data for Belts Machine

III. Building area

The term "specifically" refers to the particular area inside a tyre production plant where distinct elements, including the tread, sidewalls, and inner liner, are brought together to form the green tyre, which denotes the tyre in its uncured state. The aforementioned procedure is often known as "tyre building" or "green tyre building."

Within the domain of construction, proficient operators or mechanised equipment meticulously arrange and place the diverse constituents in accordance with the predetermined design and requirements of the tyre. The aforementioned procedure facilitates the production of an environmentally friendly tyre that is prepared for the subsequent curing phase, during which it will be subjected to thermal and compressive treatment in order to attain its ultimate structure and characteristics.

The determination of the building area plays a vital role in the tyre manufacturing process, as it establishes the fundamental basis for the ultimate attributes of the tyre, including its dimensions, tread design, and overall composition. The correct assembly during this phase is crucial in order to guarantee that the tyre conforms to performance, safety, and quality criteria subsequent to its curing process (see Fig. 3.3).

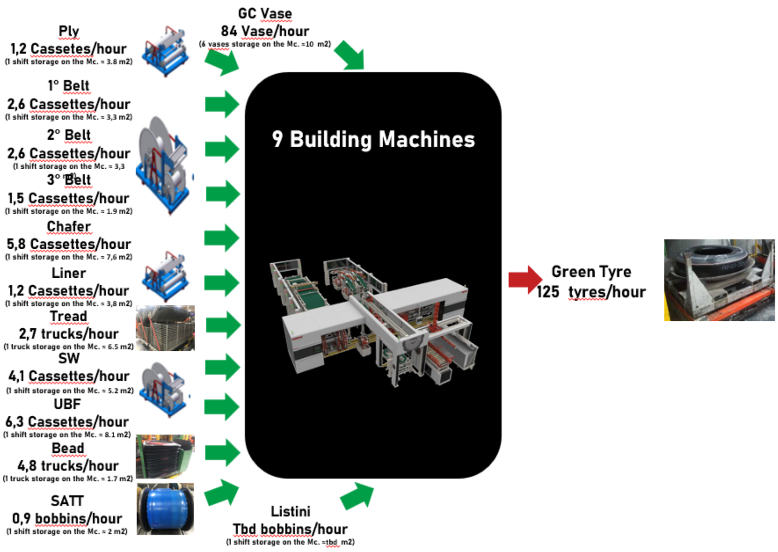


Figure 3.21. MESNAC MACHINE Requirements

3.3 Defining the Used Flexsim Features

1. **ForKlift**
   The forklift is a mechanised apparatus used for the purpose of elevating and transporting various items in a simulated setting. The device has the ability to elevate objects at various heights and is often used in simulations pertaining to warehousing and logistics operations. The forklift has a great degree of flexibility, enabling users to establish various parameters such as lift capacity, lift speed, and destination places.

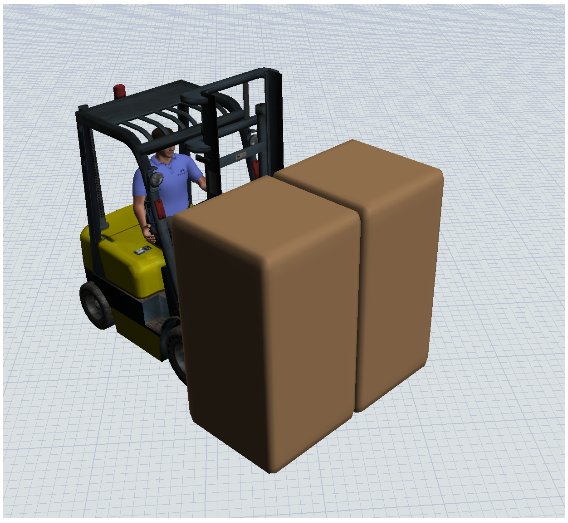


Figure 3.22. forklift

2. **Operator**
   The Transporter entity is a constituent element inside the FlexSim software platform, embodying a human operator who assumes the role of material transportation and task execution within a simulated model. This particular component is often used in situations that require the involvement of a human operator for manual intervention or decision-making, such as in the context of material handling activities.

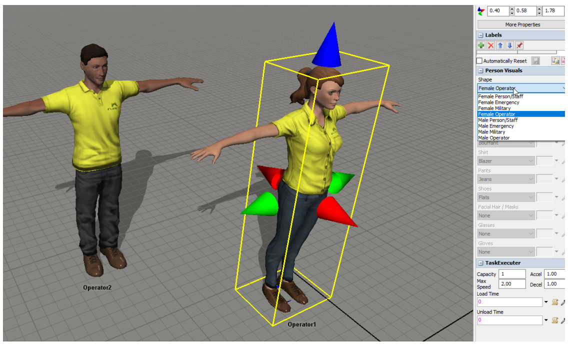


Figure 3.23. Operators

3. **Queues**
   Queues in FlexSim serve as virtual holding spaces where things or entities are temporarily kept until they may undergo processing or be transferred to the subsequent stage inside a simulation model. Queues are of paramount importance in the modelling of processes characterised by waiting periods, such as manufacturing lines, service systems, and logistics.

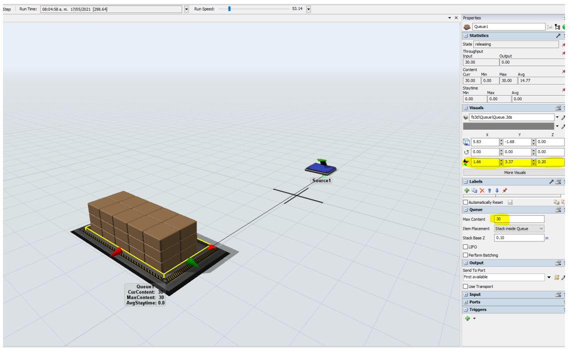


Figure 3.24. Accumulation of Item in the Queue

4. **Separator**
   The separator component inside the FlexSim software is used to divide a continuous flow of things or entities into various streams, depending upon predetermined requirements or criteria. This feature proves to be quite advantageous when used to modelling situations that involve the sorting or routing of objects along various channels inside a system (see Fig.3.25).

5. **Combiner**
   The Combiner component in FlexSim serves as the complementary equivalent to the Separator component. The process involves the consolidation of several streams of goods or entities into a unified flow. This feature proves to be advantageous in simulation scenarios where the amalgamation of elements is required prior to advancing to further stages of a given process.

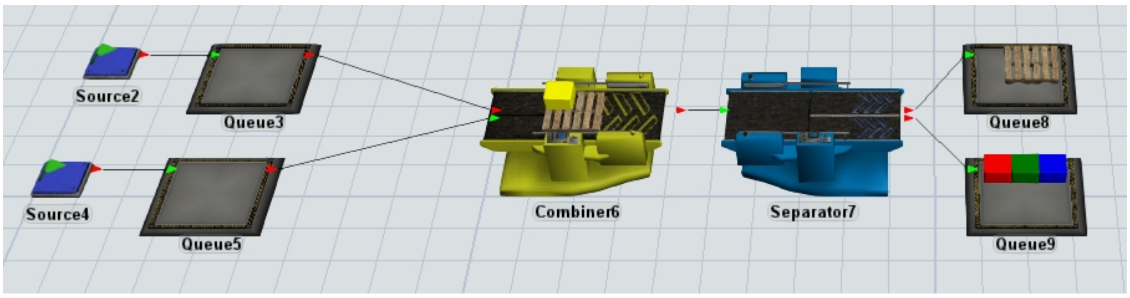


Figure 3.25. Palletizing and Separating Boxes

6. **Walls**
   In the context of FlexSim, walls are used to represent tangible obstructions or divisions inside a simulation model. The purpose of their use is to establish the arrangement and framework of the simulated milieu. The presence of walls contributes to the creation of an authentic portrayal of the physical environment and

has an impact on the dynamics of movement and interactions among things.

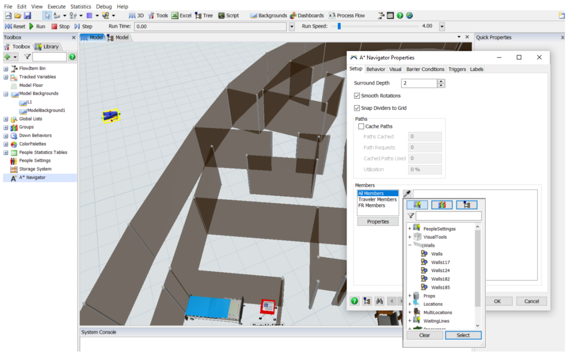


Figure 3.26. 3D presentation of the Walls

7. **Barriers**
   Barriers inside the FlexSim framework provide a comparable role to conventional barriers, however, with the added capability of being dynamic and adaptable. During a simulation run, barriers have the ability to alter their location or orientation in response to certain situations or programmed logic. This characteristic makes them especially valuable for simulating situations in which impediments have the potential to undergo dynamic changes.

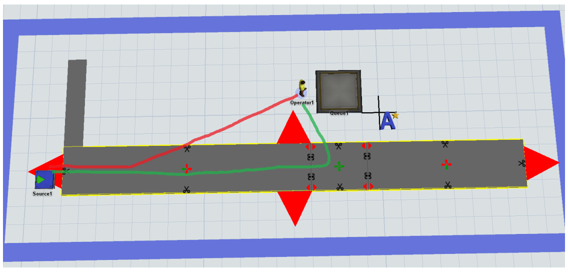


Figure 3.27. Barriers Presentation

Chapter 4

Model Set Up

4.1 Methodology

In previous discussions, I have addressed the many segments within the tyre business and provided definitions for the objects used in modelling the factory. In this part, we will examine the interconnections established among these segments and explore the technique employed to effectively control the flow between them.

Fundamentally, we should understand the difference between S-connection and A-connection. In FlexSim, the term **"A Connection"** is an abbreviation for **"Arrow Connection."** The connection referred to is a kind of linkage used for the purpose of connecting items inside a simulation model. Connections are often used to symbolise the pathways or routes that link various components inside the model. In simulation models, arrows connecting one object to another frequently represent the flow of physical entities or things, expressing the direction of flow.

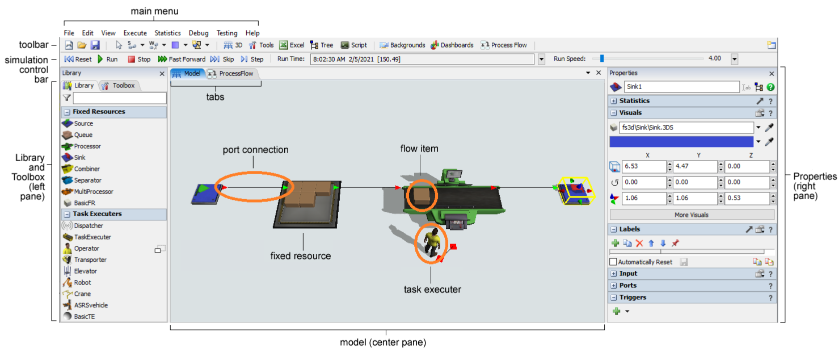


Figure 4.1. Flow of item using A-connection

In FlexSim, the term **"S Connection"** is an abbreviation for **"Signal Connection."** The connection in question is a kind of linkage used to symbolise the transmission of information or signalling between distinct components inside a simulation model. Connections serve as a means of transmitting information, data, or signals between various items. Dashed lines are often used to depict the connection between things, symbolising the transmission of information or signals rather than actual entities.

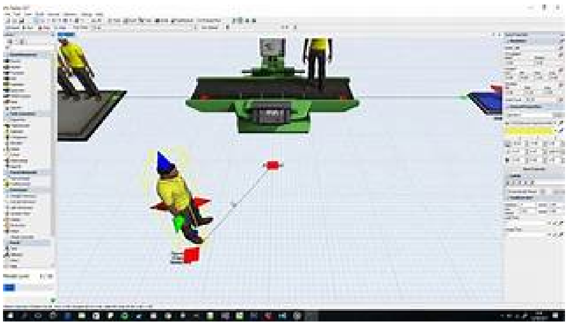


Figure 4.2. Flow of information using S-connection

Now I will discuss in detail the methodology of connection and logic that I have used:

1. There will be **A connection** from the outside supplies to the warehouse storage. These supplies are shown by the sources (see Fig.4.3), and the rate at which the sources arrive follows an exponential distribution with 10 seconds. However, in reality, we need to import the SQL query in Python to see the exact form of the distribution (exponential, normal), which is out of the scope of the thesis.

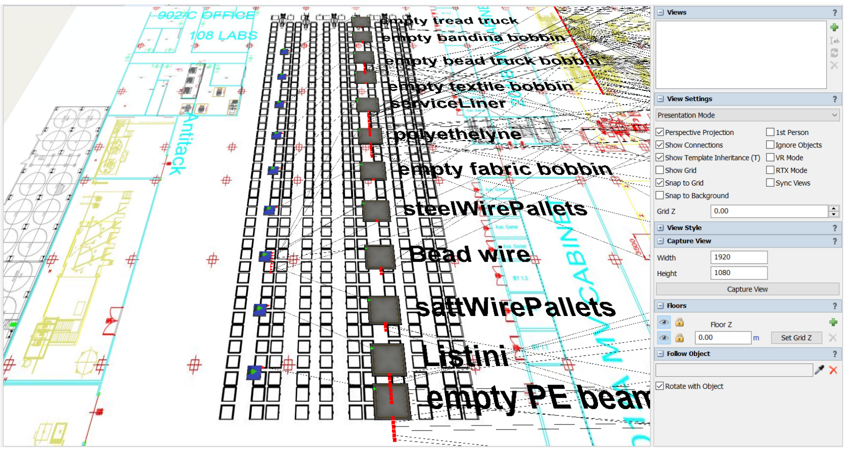


Figure 4.3. A-connection between sources or supplies to warehouse raw materials storage

2. There will be an S connection between the raw material queues and the dispatcher from one side, and also from this dispatcher to the input queues for the semi-finishing machines. The dispatcher object helps in big projects because it is a pivotal

component responsible for coordinating entity flow within a simulation model. It assigns tasks to available resources based on predefined rules, manages task priorities, controls entity queues, and makes routing decisions. Additionally, the dispatcher allocates resources efficiently, balances workloads, adapts to dynamic conditions, and provides feedback on performance metrics. It also allows for customization of dispatching logic to suit specific simulation requirements. Overall, the dispatcher plays a crucial role in simulating and optimizing complex systems by facilitating effective resource allocation and task scheduling. We also need to pay attention while we are making the connection with the dispatcher because we will use the two types: **from the dispatcher to the transporters we use A connection, and between the same dispatcher and the input queue we use S connection**, see the following figure for more clarification there are both A-connection From Dispatcher to the 4-klifts, and S-connection between the dispatcher and the input Queues.

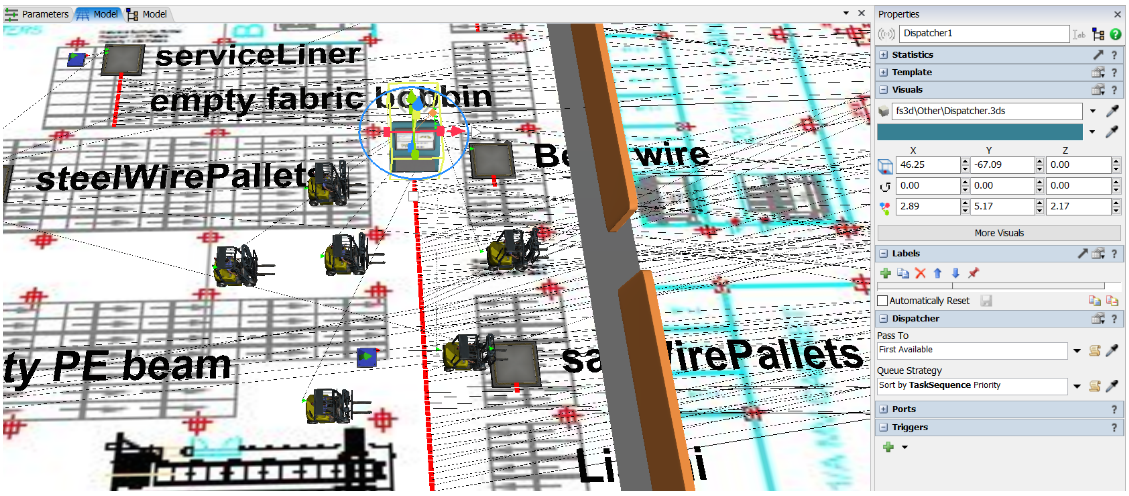


Figure 4.4. A-connection and S-connection

3. Before we proceed to the 3D presentation of the logic made for the machines (see Fig. 4.7), I will discuss the logic used for all machines in the semi-finishing area and in the building area.
   In general, for each machine to produce the required output, it must receive the required inputs, which are called requirements. You can check these data in Section **3.2 Data Collection for the Machines**. For example, for Metallic Calender, you can check Fig3.11. **Below, you can check all of the calculations done regarding this logic:**

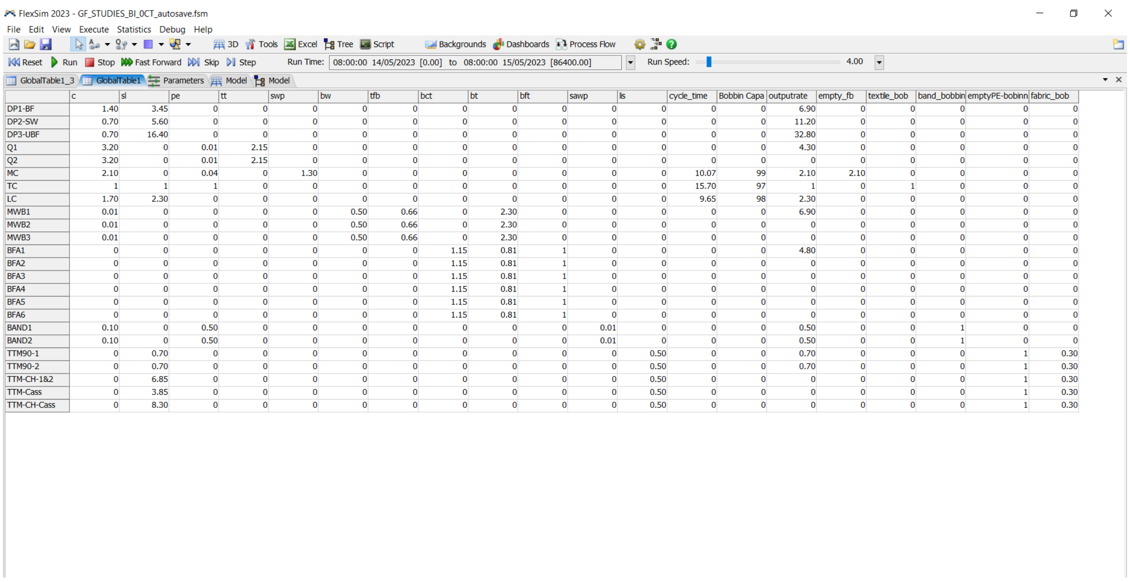
   - The first column includes the requirements for each machine.

   - The second column includes the required output.

- In the third column, which includes the portion of each input in terms of output, we obtain these numbers by simply dividing each input by the output.
- The fourth column includes the spliter. I am using the spliter in order to make all the divided numbers whole numbers by simply multiplying each number by 1000, or the smallest number, which makes the smallest number a whole number.
- The combiner, which is a representation of the fifth column, represents the machine's cycle time.
- By using this logic and steps, we can make the proper mixture of these requirements in order to produce the final output, noting that this is only happening logically and not physically.

Q_INPUT	Q_OUTPUT	portion needed in terms of output	Spliter (No CT)	Compiner CT	Units
Metallic Calender					
				time taken for producing one tire * number of tire that bonin can produce = number produced in one day/24 =production per hour	
2.1	2.1	1	1000	1/number of tire * 60 = CT mins	
0.04		0.019047619	19.04761905	175.4166667	Ty/h
2.1		1	1000	0.005700713	h/Ty
1.3		0.619047619	619.047619	0.342042755	min/Ty
				20.52256532	sec/Ty
				1867.553444	haneq.sec/Ty
Liner Calender					
1.7	2.3	0.739	739.1304348	255.625	Ty/h
2.3		1.000	1000	0.00391198	h/Ty
				0.234718826	min/Ty
				14.08312958	sec/Ty
				1380.146699	haneq.sec/Ty
QUADRUPLEX_Treads					
6	4.3	1.395348837	1395.348837	96.04166667	Ty/h
4.3		1	1000	0.010412148	h/Ty
0.02		0.004651163	4.651162791	0.62472885	min/Ty
				37.48373102	sec/Ty
				1649.284165	haneq.sec/Ty
QUADRUPLEX_BF					
6	4.3	1.395348837	1395.348837		Ty/h
4.3		1	1000		h/Ty
0.02		0.004651163	4.651162791		min/Ty
					sec/Ty
					haneq.sec/Ty
DUPLEX_SW					
1.4	11.2	0.125	125	161.9166667	Ty/h
11.2		1	1000	0.006176016	h/Ty
				0.370560988	min/Ty
				22.23365929	sec/Ty
				644.7761194	haneq.sec/Ty
DUPLEX_BF					
2.8	6.9	0.405797101	405.7971014	228.7916667	Ty/h
6.9		1	1000	0.004370789	h/Ty
				0.262247314	min/Ty
				15.73483883	sec/Ty
				1038.499363	haneq.sec/Ty
DUPLEX_UBF					
1.4	32.8	0.042682927	42.68292683	288.9166667	Ty/h
32.8		1	1000	0.003461206	h/Ty
				0.207672339	min/Ty
				12.46034035	sec/Ty
				236.7464667	haneq.sec/Ty
3 Monowire Bead					
0.02	6.9	0.002898551	2.898550725	53.54166667	Ty/h
1.5		0.217391304	217.3913043	0.018677043	h/Ty
6.9		1	1000	1.120622568	min/Ty
				67.23735409	sec/Ty
				1680.933852	haneq.sec/Ty
6 Bead Filler					
6.9	4.9	1.408163265	1408.163265	19.20833333	Ty/h
4.9		1	1000	0.052060738	h/Ty
1		0.204081633	204.0816327	3.123644252	min/Ty
				187.4186551	sec/Ty
				4685.466377	haneq.sec/Ty
2 TTM_PLY Cutting					
0.6	1.4	0.428571429	428.5714286	94.41666667	Ty/h
1.4		1	1000	0.01059135	h/Ty
				0.635481024	min/Ty
				38.12886143	sec/Ty
				3698.499559	haneq.sec/Ty
1 Belt					
0.6	13.7	0.04379562	43.79562044	331.1666667	Ty/h
13.7		1	1000	0.003019628	h/Ty
1		0.072992701	72.99270073	0.181177655	min/Ty
				10.87065929	sec/Ty
				500.0503271	haneq.sec/Ty
2 Belt					
0.6	13.7	0.04379562	43.79562044	405.9166667	Ty/h
13.7		1	1000	0.00246356	h/Ty
1		0.072992701	72.99270073	0.147813591	min/Ty
				8.868815438	sec/Ty
				407.9655102	haneq.sec/Ty
3 Cassettes					
0.6	7.7	0.077922078	77.92207792	405.9166667	Ty/h
7.7		1	1000	0.00246356	h/Ty
1		0.12987013	129.8701299	0.147813591	min/Ty
				8.868815438	sec/Ty
				718.3740505	haneq.sec/Ty
Chafer cassette					
0.6	16.6	0.036144578	36.14457831	206.7916667	Ty/h
16.6		1	1000	0.004835785	h/Ty
1		0.060240964	60.24096386	0.290147088	min/Ty
				17.40882531	sec/Ty
				348.1765061	haneq.sec/Ty
2 Bandina					
0.2	1	0.2	200	63.375	Ty/h
0.02		0.02	20	0.015779093	h/Ty
				0.946745562	min/Ty
				56.80473373	sec/Ty
				7895.857988	haneq.sec/Ty

4. **Global Table:** Several objects and components inside a simulation model may access a global table, which is a common data structure. This feature is available in FlexSim. It functions as a centralized repository for storing and transmitting information across the various elements of the model, making it possible for data to be dynamically modified while simulations are being conducted. This flexible tool offers support for a variety of data formats, which enables it to be integrated with parts of logic and control flow in order to make choices and set off actions. Users are able to compare various collections of data or parameters thanks to global tables, which are an essential component of scenario analysis and experimentation. In addition to this, they make reporting, visualization, and analysis easier, therefore supplying very helpful insights into the functioning of the simulated system. For instance, a global table may be used in manufacturing simulations to record product information such as production durations and resource needs, which would then influence choices about the scheduling of production and the distribution of resources. So that I can insert all of the requirements in a global table and use it to parameterize all of these requirements: To parameterize any value, you can simply



	c	sl	pe	tt	swp	bw	tfb	bct	bt	bft	sawp	lis	cycle_time	Bobbin Capa	outputrate	empty_fb	textile_bob	band_bobbin	emptyPE-bobinn	fabric_bob
DP1-BF	1.40	3.45	0	0	0	0	0	0	0	0	0	0	0	0	6.90	0	0	0	0	0
DP2-SW	0.70	5.60	0	0	0	0	0	0	0	0	0	0	0	0	11.20	0	0	0	0	0
DP3-UBF	0.70	16.40	0	0	0	0	0	0	0	0	0	0	0	0	32.80	0	0	0	0	0
Q1	3.20	0	0.01	2.15	0	0	0	0	0	0	0	0	0	0	4.30	0	0	0	0	0
Q2	3.20	0	0.01	2.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MC	2.10	0	0.04	0	1.30	0	0	0	0	0	0	0	10.07	99	2.10	2.10	0	0	0	0
TC	1	1	1	0	0	0	0	0	0	0	0	0	15.70	97	1	0	1	0	0	0
LC	1.70	2.30	0	0	0	0	0	0	0	0	0	0	9.65	98	2.30	0	0	0	0	0
MWB1	0.01	0	0	0	0	0.50	0.66	0	2.30	0	0	0	0	0	6.90	0	0	0	0	0
MWB2	0.01	0	0	0	0	0.50	0.66	0	2.30	0	0	0	0	0	0	0	0	0	0	0
MWB3	0.01	0	0	0	0	0.50	0.66	0	2.30	0	0	0	0	0	0	0	0	0	0	0
BFA1	0	0	0	0	0	0	0	1.15	0.81	1	0	0	0	0	4.80	0	0	0	0	0
BFA2	0	0	0	0	0	0	0	1.15	0.81	1	0	0	0	0	0	0	0	0	0	0
BFA3	0	0	0	0	0	0	0	1.15	0.81	1	0	0	0	0	0	0	0	0	0	0
BFA4	0	0	0	0	0	0	0	1.15	0.81	1	0	0	0	0	0	0	0	0	0	0
BFA5	0	0	0	0	0	0	0	1.15	0.81	1	0	0	0	0	0	0	0	0	0	0
BFA6	0	0	0	0	0	0	0	1.15	0.81	1	0	0	0	0	0	0	0	0	0	0
BAND1	0.10	0	0.50	0	0	0	0	0	0	0	0.01	0	0	0	0.50	0	0	1	0	0
BAND2	0.10	0	0.50	0	0	0	0	0	0	0	0.01	0	0	0	0.50	0	0	1	0	0
TTM90-1	0	0.70	0	0	0	0	0	0	0	0	0	0.50	0	0	0.70	0	0	0	1	0.30
TTM90-2	0	0.70	0	0	0	0	0	0	0	0	0	0.50	0	0	0.70	0	0	0	1	0.30
TTM-CH-1&2	0	6.85	0	0	0	0	0	0	0	0	0	0.50	0	0	0	0	0	0	1	0.30
TTM-Cass	0	3.85	0	0	0	0	0	0	0	0	0	0.50	0	0	0	0	0	0	1	0.30
TTM-CH-Cass	0	8.30	0	0	0	0	0	0	0	0	0	0.50	0	0	0	0	0	0	1	0.30

Figure 4.5. Global Table of the Inputs

add a label with a proper abbreviation for the input. For example, in the following figure, I have used bct for Bead Coil Truck. Then, by using the dropper in the label section, you can go and select the desired input value.

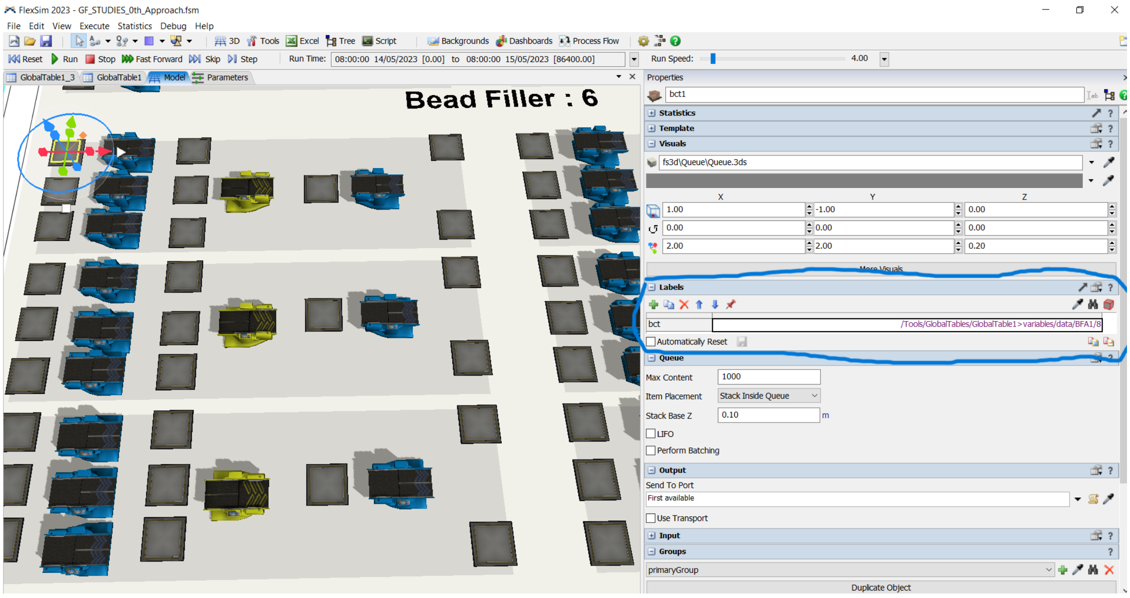


Figure 4.6. Parameterize the Inputs

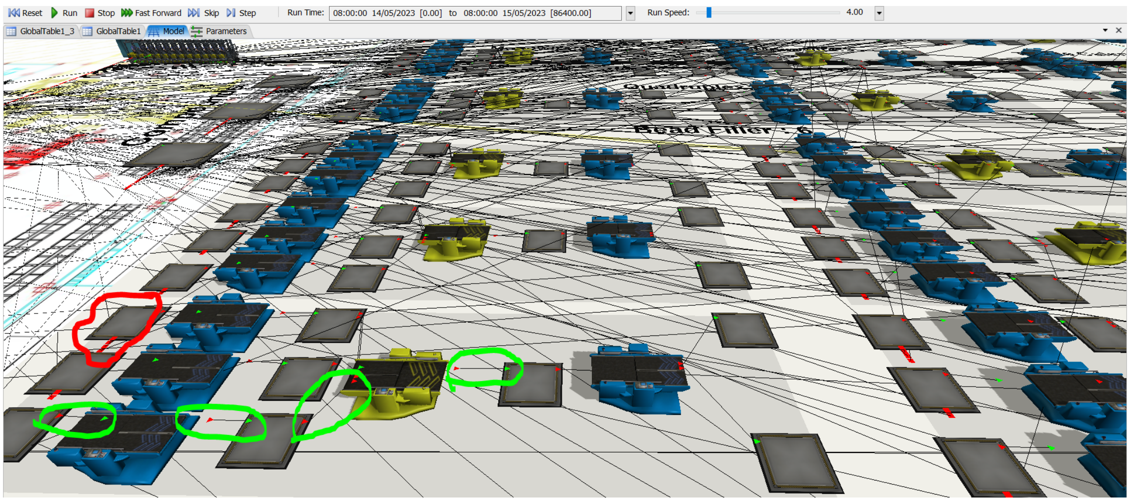


Figure 4.7. 3D presentation for the Logic

4.2 Creation of the Process Flow

I am using process flow in order to deliver the requirements for each machine (see Fig. 4.6) from the warehouse to the input queues of the semi-finishing machines and also to take the products of the semi-finishing machines to the intermediate queues, which will take the MESNAC machines in the building area to produce the green tires, which is the step before curing (see Fig. 3.4).

Now let's see in detail the steps of the logic I used in this project, noting that the properties of each activity are shown on the right side of the figures.

1. **Source:** There are many ways to generate tokens in the process flow, and a token simply represents the material, so that the flow of tokens in the process flow is the flow of materials in the model (factory). In this process flow, I used an inter-arriving source, which generates one token every hour.

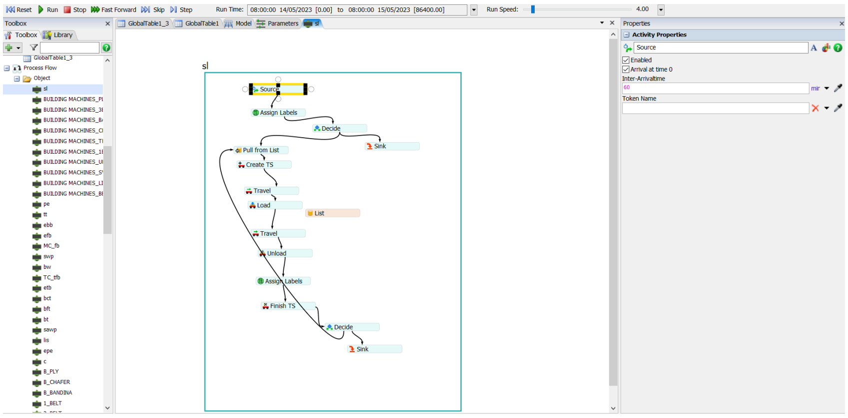


Figure 4.8. Source is generating the token

2. **First Assign Labels:** In this crucial step, I am giving a label to the token as "REQUIRED" (see Fig.4.9) in order to access the required inputs for the machine, which are presented by the label given to the input queues for each machine. For example, in this Fig.4.6, the token will take the value of bct (bead coil truck), and its name will be changed from "token" to "REQUIRED", and the value of bct is parameterized in this Global Table Fig.4.5.

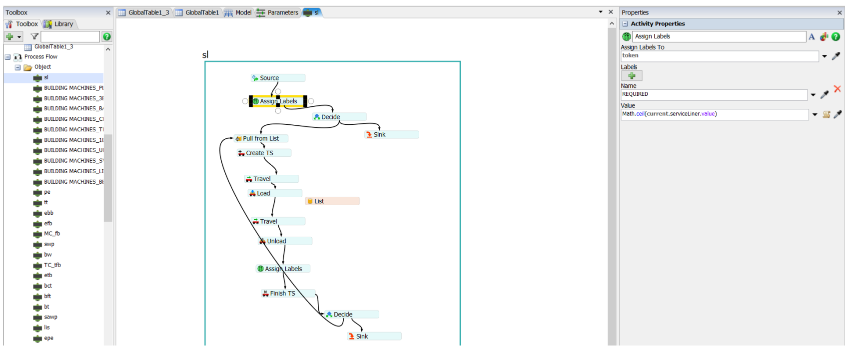


Figure 4.9. Assign Labels To Access Machines Requirements

3. **First Decision Point:** The first decision point is not actually required, but it is just to avoid mistakes and confusion by flexsim because there are hundreds of inputs in this project, and it is the same as Decision Point 2, which will be discussed in the flowing steps.

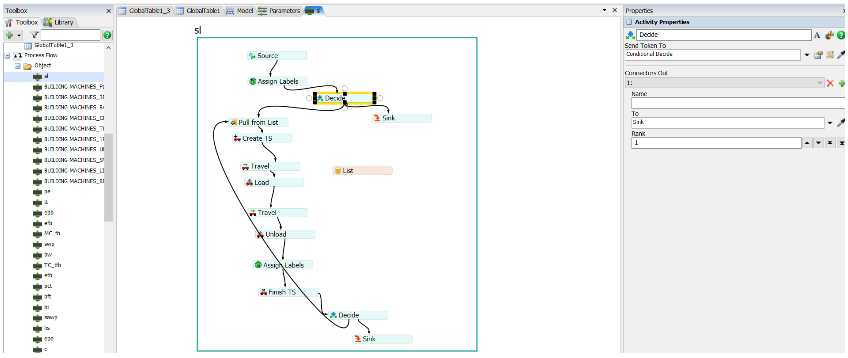


Figure 4.10. First Decision Point

4. **Pull From The List:** I had created a list for each material or product in order to push the outputs inside it and not to other 3D components (see Fig. 4.10). I am using this in order to increase the saturation of the transporters because they will not be waiting for new items to enter the queue in order to load them, and in this way, the material will always be available.

   In this elaborated example, the token "REQUIRED" will be pulled from the list of service lines (see Fig. 4.11), where we can also notice the other lists to the left of the figure.

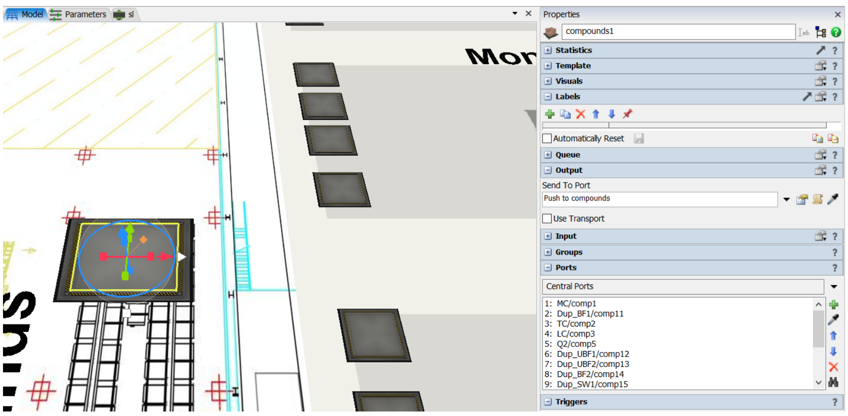


Figure 4.11. Push to the List

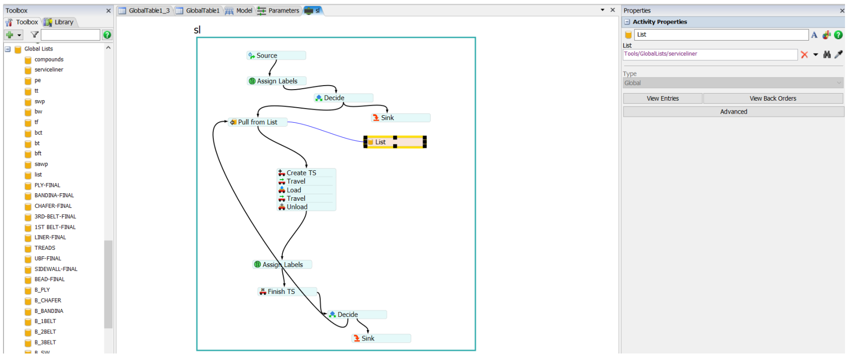


Figure 4.12. Pull from the List

5. **Creating the Task Sequence for the Transporters:** As the name indicates, in this step I am defining the path of the activities that should be done by the forklifts, but the S-connections must be made before (see Fig.4.12), where we can see that the first connection is made by the dispatcher and the second one for the material queue.

   Create TS: By writing current.centerObjects[**1**] inside Task Excuter, we assign the task of managing the movements of the transports to the dispatcher, which will optimize them according to different factors like distance travel and requirements, where **current** is the object that the process flow made for, which is the input queue for the machine in this case, and **centerObjects**[**1**] is the dispatcher (see Fig.4.13).

   Travel to Loading Point: By writing current.centerObjects[**2**] inside Destination, we are indicating the queue where the transporter should travel in order to load the material, knowing that the **current** is the object that the process flow made for which is the input queue for the machine in this case, and **centerObjects**[**2**] is Destination (see Fig.4.13).

   Travel Back: We write only current to tell the dispatcher to give order to the transporters to travel back to the input queue which the process flow attached to (see Fig.4.13), and then transporter should unload the shipment, and at this point we should end the task sequence (Travel-Load-Travel-Unload-End)

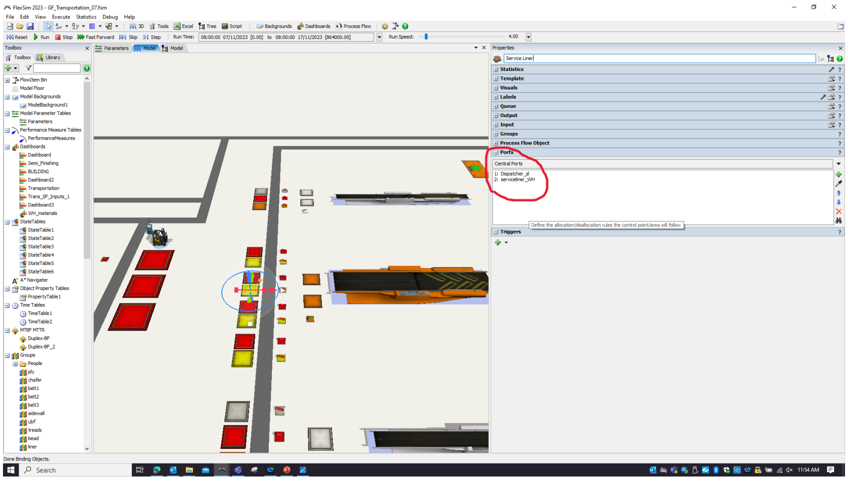


Figure 4.13. S-Connections

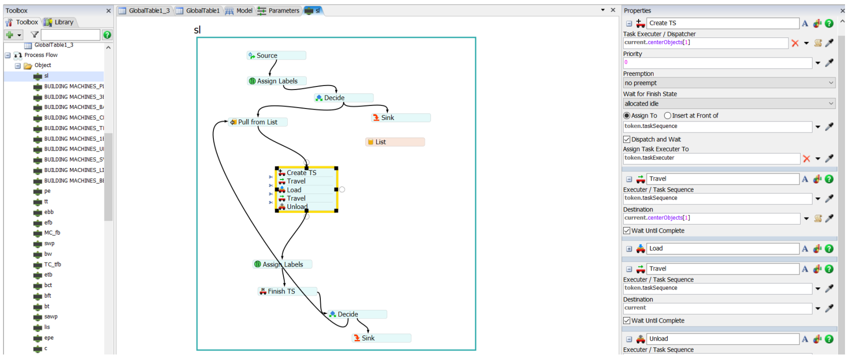


Figure 4.14. Transportation Task Sequence

6. **Second Assign Labels:** The only difference from the first one is that the value should be a token. REQUIRED-1, which means that since the transporter already took one item , the next REQUIRED amount should be decreased by one.

7. **Second Decision point:** This decision point is crucial, and without it, the logic will change from supplying the machines with a limited amount to an unlimited amount, because in this step, I am telling the token to go to the sink (will be deleted) in the case token.REQUIRED = 0 (see Fig.4.16) , so in other words, if the required amount by the machine is reached, delete the token; otherwise, go again and pull from the list another item, Do not forget that this is happening because we are subtracting one from the required amount at each loop (see Fig.4.15)

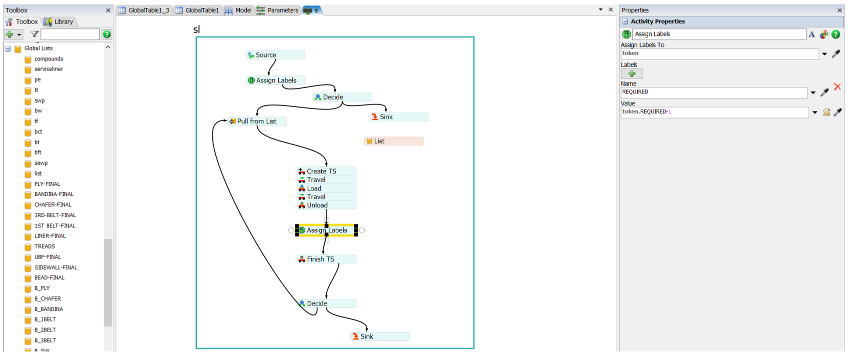


Figure 4.15. Decreasing the Required Amount

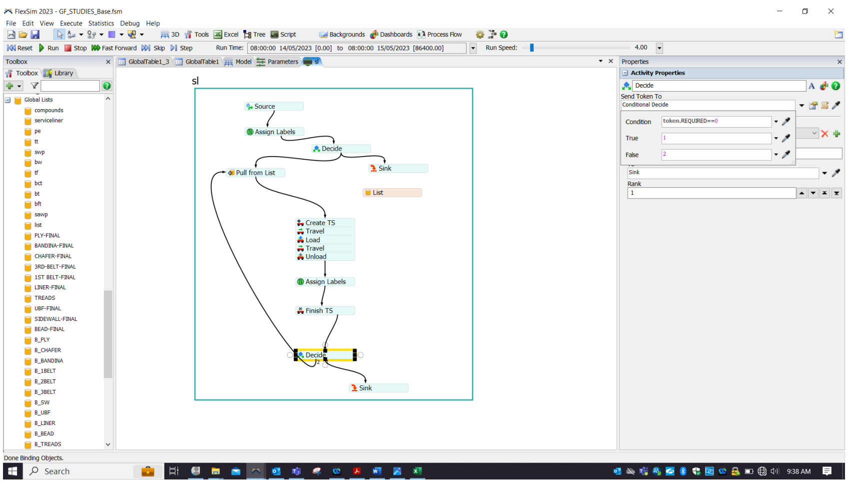


Figure 4.16. Second Decision Point

4.3 Logic Testing

After modelling the machines, assigning the requirements to their inputs, and attaching these inputs to the process flows, it is time to test the logic by simply running the model for one day and making comparative analysis with the inputs made by the industrial engineering team and discussed previously in Chapter 3.2, "Data Collection," for example: see Fig.3.11, It is noteworthy to mention that this step took two to three weeks in order to change the color of the cells from red (wrong values) to green (meeting the requirements), and running takes time , and you need to check the values at each trailer, I also had used 15 transporter at general face just to make sure that this is able to deliver the requirements regardless of the real distance and the number of transporters as shown in Fig.4.18

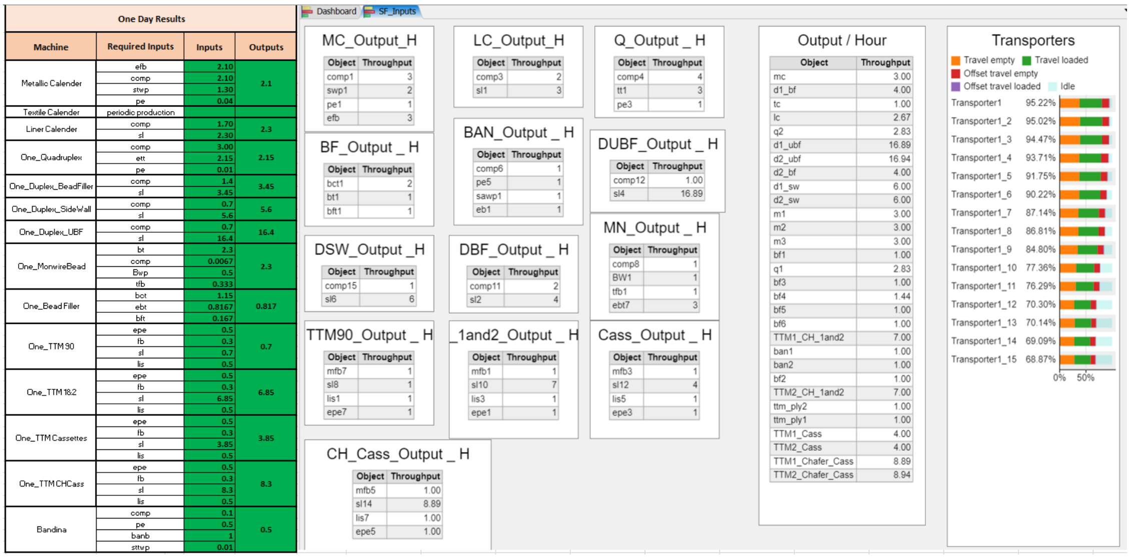


Figure 4.17. Comparative Analysis-Logic Testing

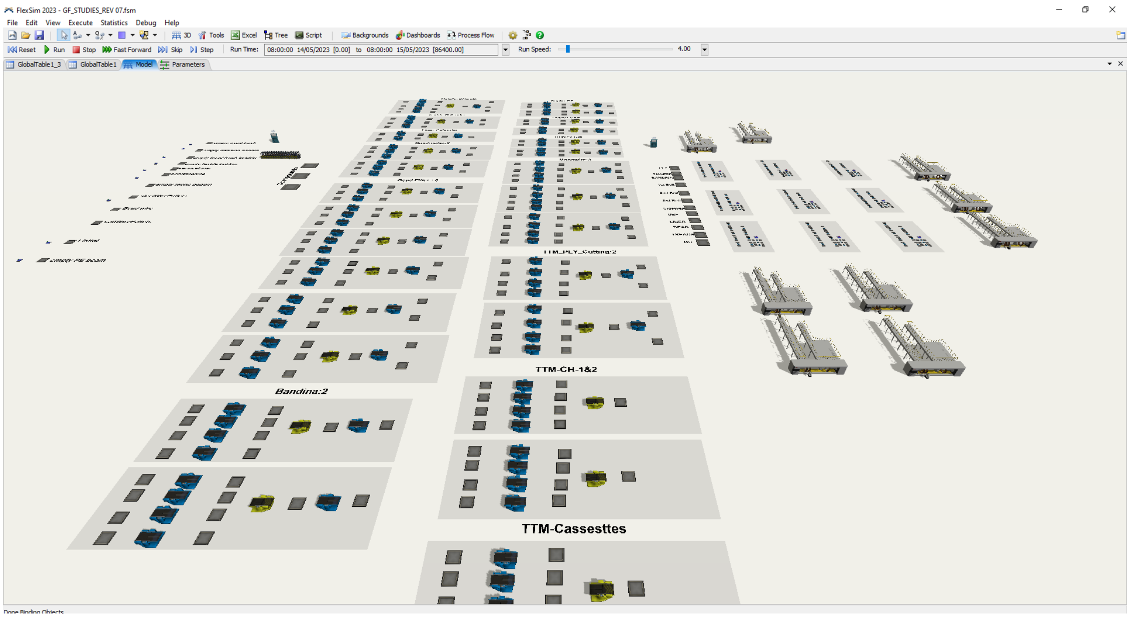
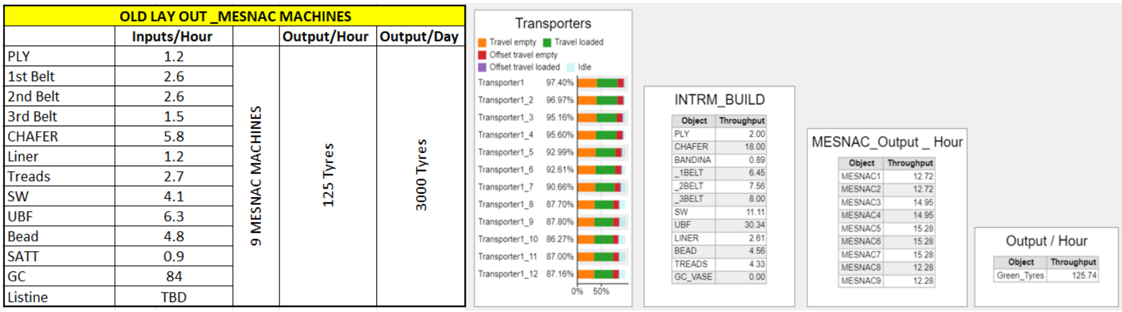


Figure 4.18. Factory Modeling: Phase Two

Its not enough to compare only the semi-finished inputs and outputs, but we also need to compare the final output of the building area to see if it meets the requirements shown in Fig.3.21, noting that at this step I had finished the modelling phase two (see Fig.4.20), and from the following figure we can see that by using this logic we are able to produce 125 green tires per hour and about 3000 per day. We can notice that the number of transporters has been reduced to 12 just because I have reduced the distance between the machines logic.



OLD LAY OUT _MESNAC MACHINES				
	Inputs/Hour		Output/Hour	Output/Day
PLY	1.2	9 MESNAC MACHINES	125 Tyres	3000 Tyres
1st Belt	2.6			
2nd Belt	2.6			
3rd Belt	1.5			
CHAFER	5.8			
Liner	1.2			
Treads	2.7			
SW	4.1			
UBF	6.3			
Bead	4.8			
SATT	0.9			
GC	84			
Listine	TBD			

Figure 4.19. Green tires Output

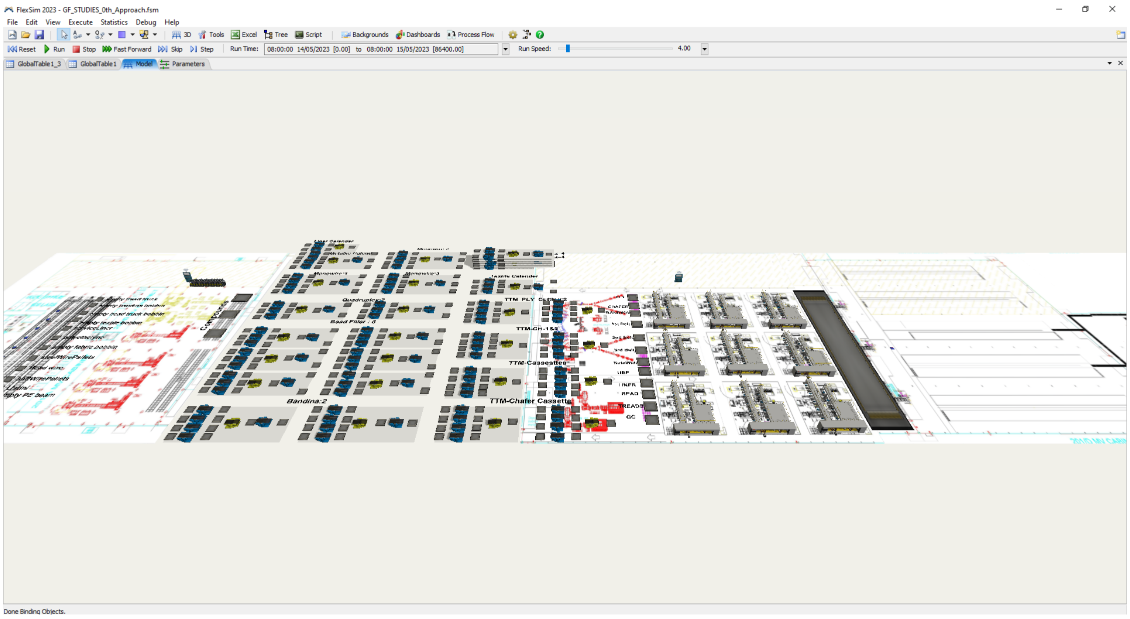


Figure 4.20. Factory Modeling: Phase Two

4.4 Implementation of the Layout

When using FlexSim, a simulation program that was developed for modelling complex systems, there are several phases involved in the process of adding a backdrop picture. In the first place, we must check that the picture is in a format that is compatible with our simulation, such as JPEG, PNG, or DWG, and that it is of a suitable size for our simulation. We may access the backdrop settings after we have entered our FlexSim model or scene. These options are often located in menus or toolbars that are labelled "Environment," "Background," or "Scene Settings" (see Fig. 4.21). Using the supplied option, upload the backdrop picture that you have prepared, and then proceed to fine-tune its location by modifying the coordinates, which are commonly referred to as "position" or "location." In addition, the scale of the picture should be adjusted so that the size of the image may be controlled inside the simulation environment. We will need to save your modifications when we have finished making these edits in order to apply the backdrop picture to our simulation model.

It is recommended that you consult the official documentation or user guide for FlexSim in order to get the most accurate and up-to-date information. This is because the particular processes and terminology may differ based on the version of FlexSim that you are using. In addition, the community forums and support channels that are affiliated with FlexSim may be very helpful tools for gaining specialised information that is based on the most recent version of the program.

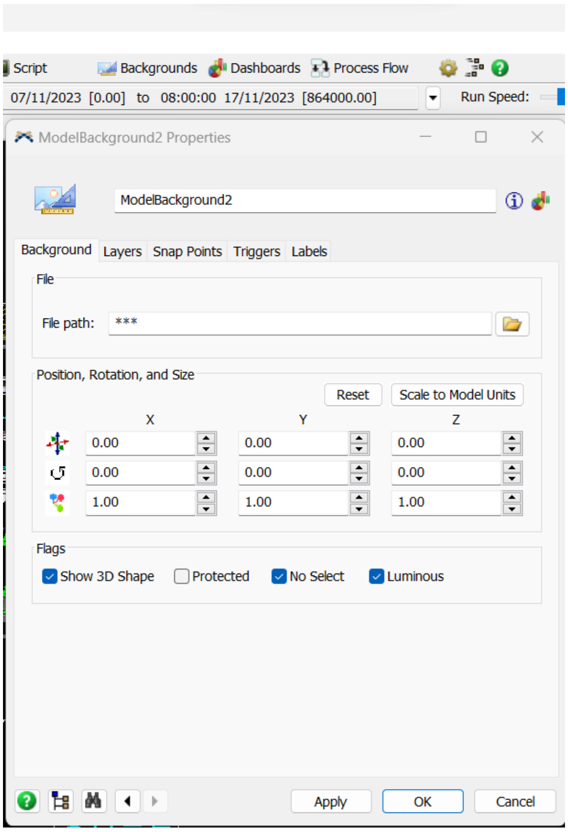


Figure 4.21. Uploading the Layout

I was working on two different formats of layouts.The first one was only a screen shot for the pdf layout because it is not heavy and I can move over it very smoothly in order to draw the baths for the transporters.

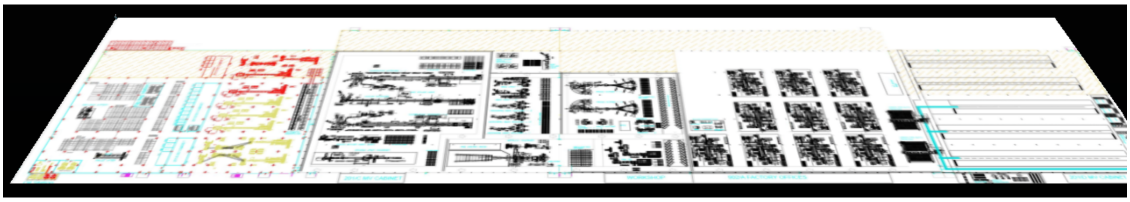


Figure 4.22. JPEG or PNG Format

The format above is sufficient only to make an analysis for transportation, but in order to get the results discussed in the last chapter, like WIP (work in progress) and handling equipment capacity, we need to upload the DWG-Autocad drawing because it contains full details (see Fig. 4.24), like the correct placement of the inputs, the exact scaling factor of the machines and the bobbins, etc.

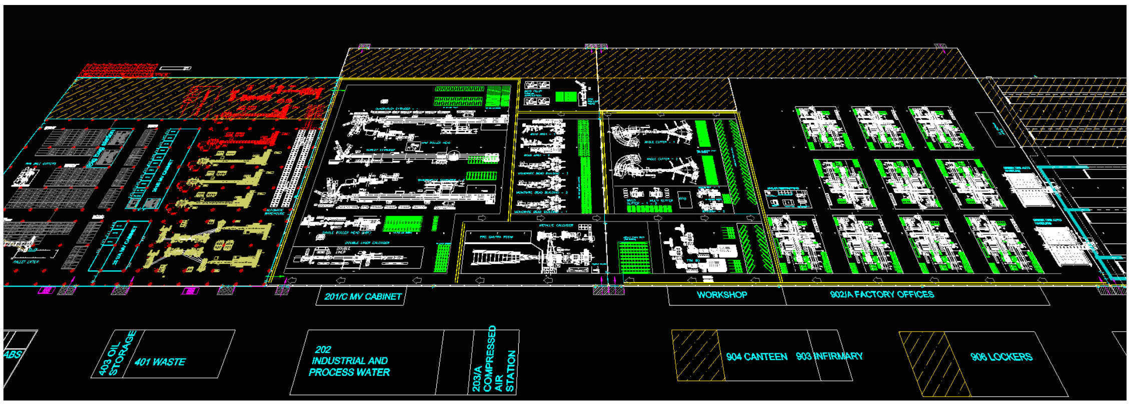


Figure 4.23. Autocad-DWG Format

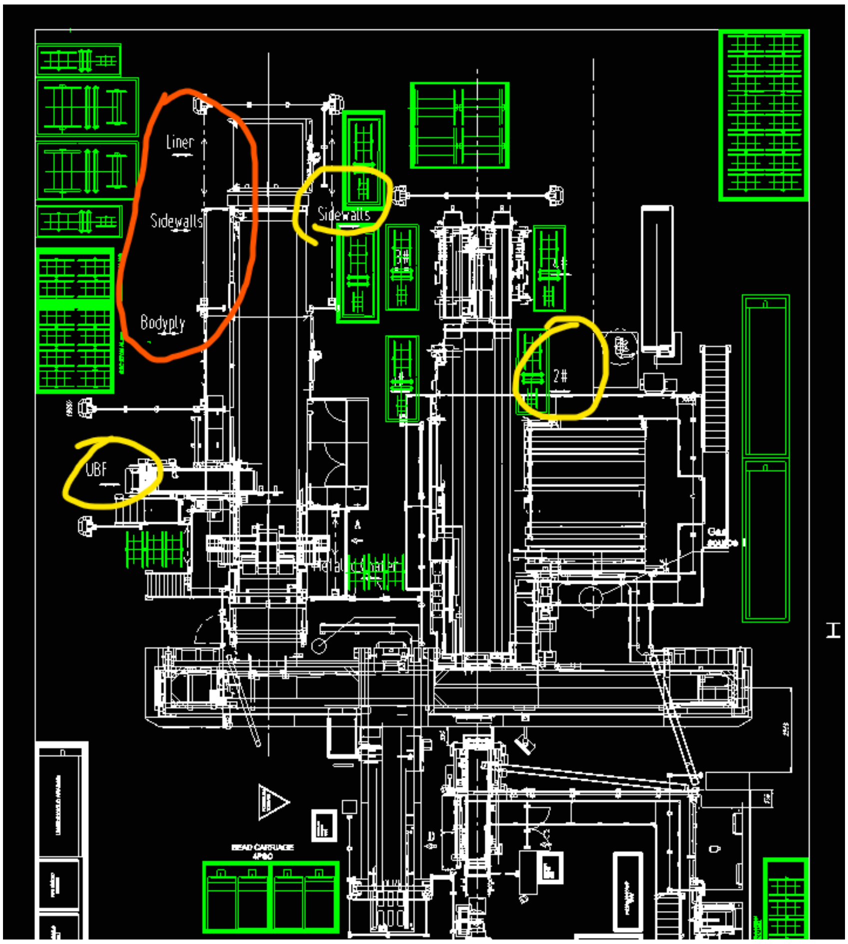


Figure 4.24. Autocad DWG-MESNAC Details

4.5 Model description

I have discussed the setup of the model and the logic used, and I have proven it so that the MESNAC machines are producing about 3000 tires per day, but I was using 12 transporters, and I have not taken the ways and the barriers into consideration.

In this section, I'll go over the model's sections, how I drew the transporter routes, and how I used the layout to arrange the machines according to a complex logic system.

The Warehouse section is the simplest to implement because I only need to put queues on the layout according to the written names with one source each, noting that the distribution type of the inter-arrival rate of the source should be driven by Python and SQL queries.

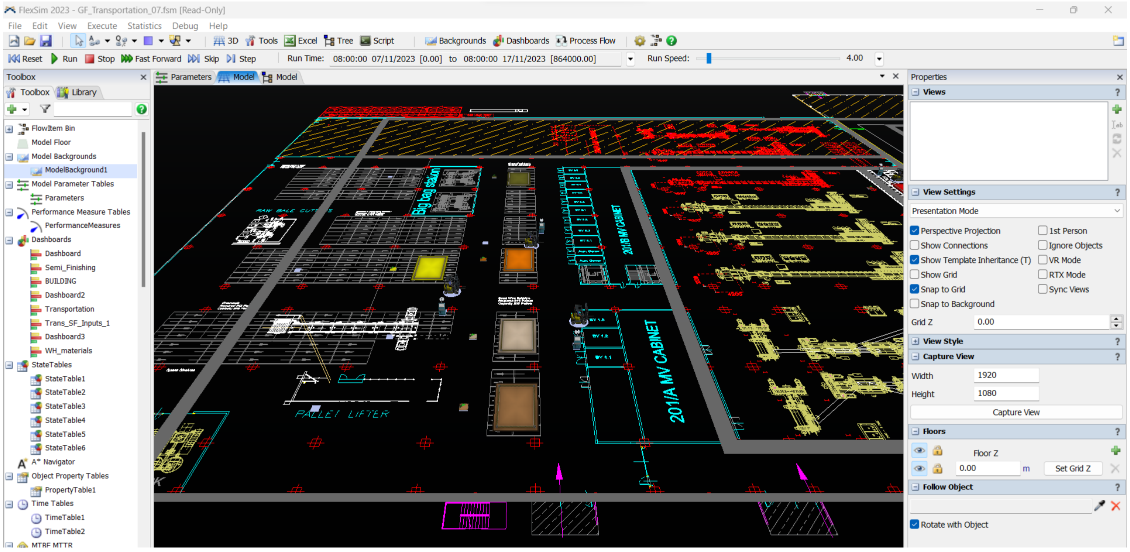


Figure 4.25. Warehouse Section

Below we have the most complex part in the tire industry, which is the semi-finishing section, where the machines get the raw materials from the warehouse to manufacture the final products that form the tire. But there are also some machines producing the semi-finishing products to be used in the same area, like the metallic calender, which is used to produce metallic fabrics that are consumed by monowire bead machines.

As we can see, the machine presentation now is very simple compared to the old presentation shown in Fig. 4.20, and this is because I have hidden all the objects related to the logic that are not present in the real case; in other words, I have kept only the machines, their inputs, and their outputs.

The final products of the semi-finishing area are getting prepared to be sent by another transporter to the 10 MESNAC machines and must be placed in the correct position in order to be taken and assembled together by MESNAC to produce 3000 green tires per day in total, which are just before curing (see Fig. 3.4).

Since we have hundreds of queues, which make mistakes in connection very likely to happen, I made a unique color for each material and product so that there is a mapping of colors between the warehouse area and semi-finishing and between the semi-finishing and building area.

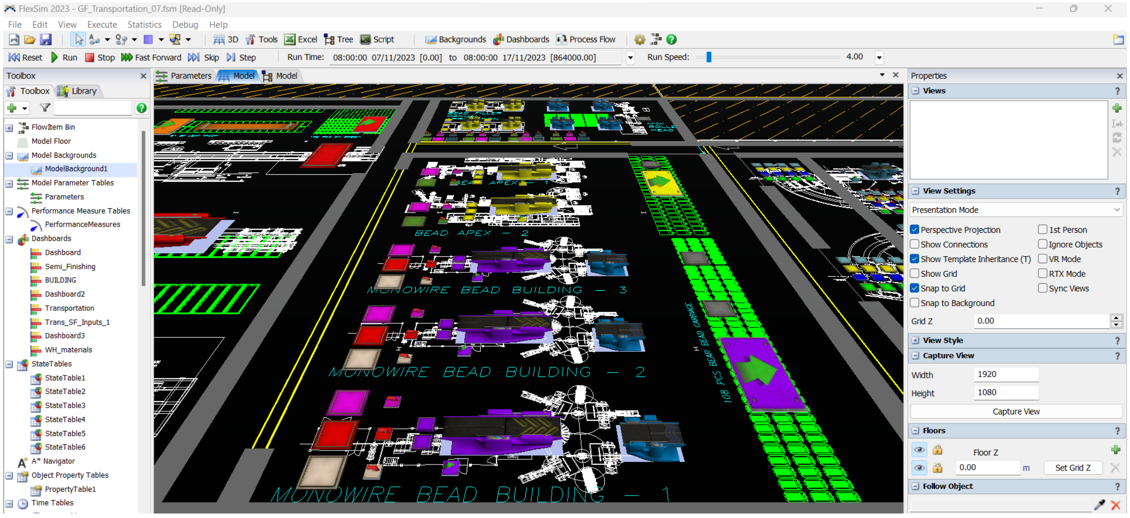


Figure 4.26. Semi-Finishing Section

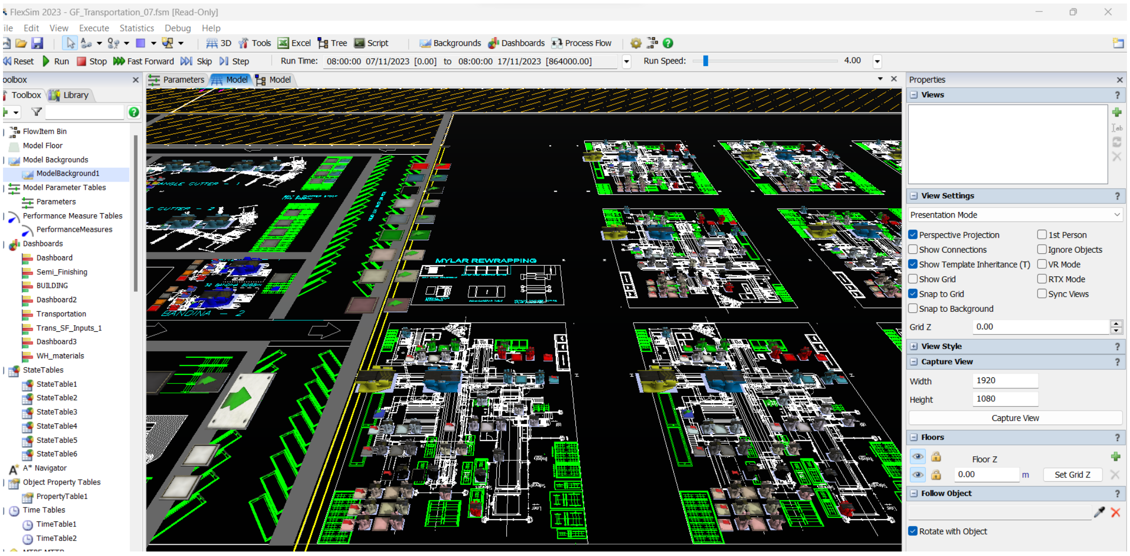


Figure 4.27. Building-MESNAC Section

After placing the machines and hiding the unwanted flexsim components, I started drawing the barriers according to the walls drawn on the layout, but since the directions that the transporters should flow were not clear, I had a discussion with the industrial engineering team, and then I made the restrictions so that they could enter from one side and exist from another side. As shown in the figure below, there is unidirectional flow in the semi-finishing area. As shown in the figure below, on each barrier there are four available directions, which I can block. Since I am making only unidirectional, there must be only one green-open arrow on each barrier placed on the corridors.

After I had finished all the modeling, I had selected all the models, including the barriers, the machines, and everything, and made an A-connection with the star navigator, which would force the transporters to follow the direction I made without crossing over the machines and the barriers and only flow in 90-degree directions (left-right-up-down).

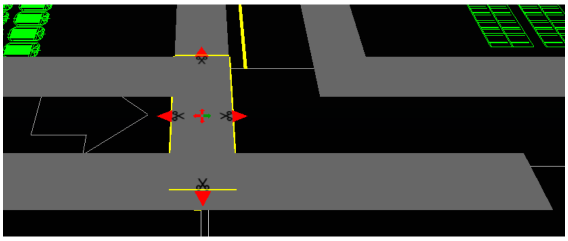


Figure 4.28. The Corridors' Barriers

Then I modeled the walls over the barriers to make the appearance more factual, as shown in the Figures below

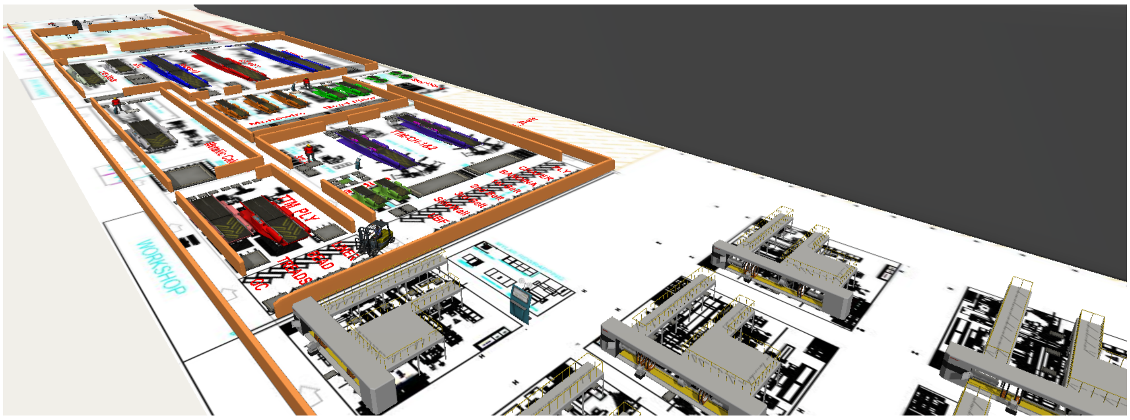


Figure 4.29. Final Internal View

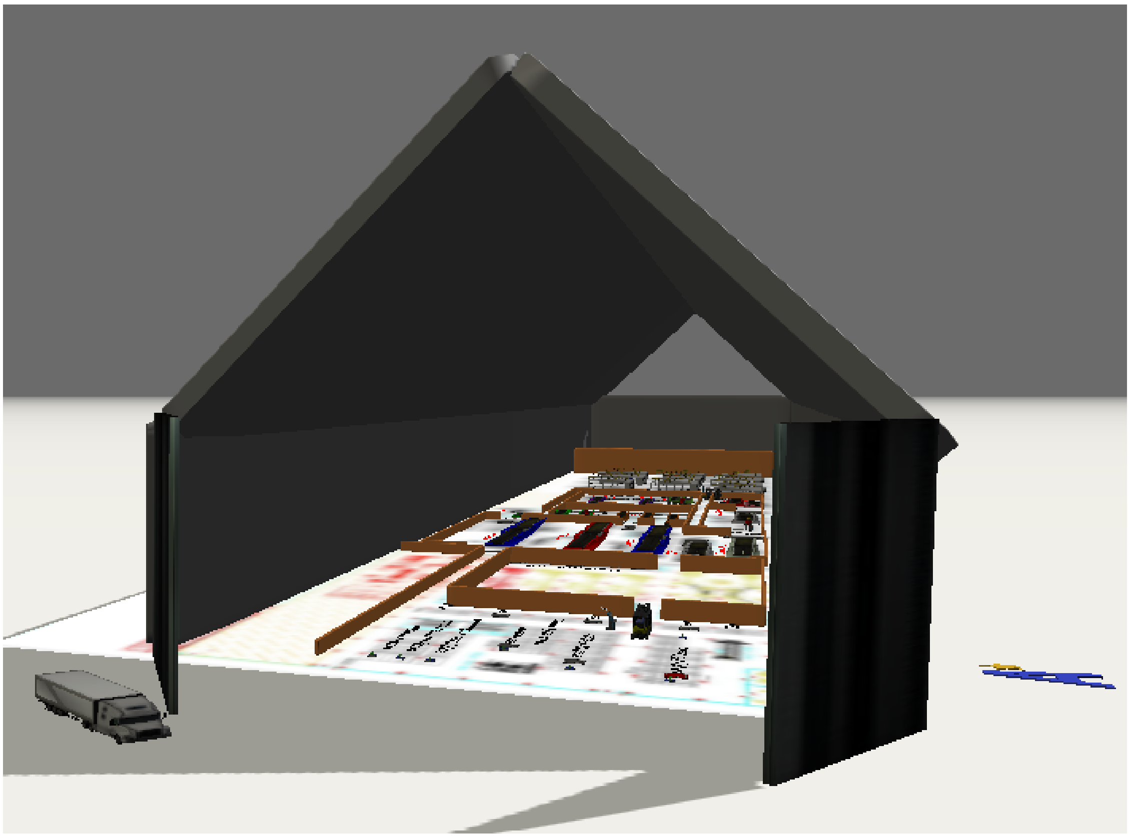


Figure 4.30. Final External View

Chapter 5

Experimental/numerical evaluation

5.1 Methodology

After I have modeled all the machines and finished the logic that indicates the process flow of the production line, I can generate all of the required results by using the dashboard tool, which allows us to track and observe all the variables and KPIs, like the inputs, outputs, machine saturation, WIP, and others, by using the following dashboards: Once

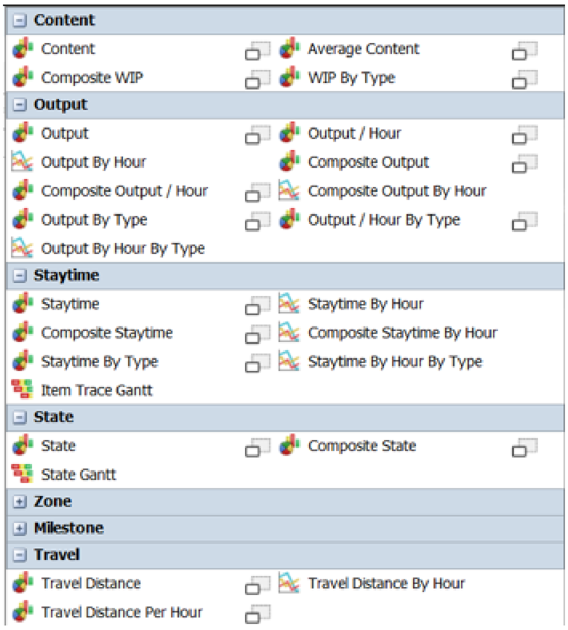


Figure 5.1. The Used Dashboards

I select the desired dashboard, I can simply attach the corresponding queues, machines, and transporters to it, and then I run the model for one day so that I can get more accurate results. And when I start comparing the different scenarios, I choose the best model according to the number of units produced per day.

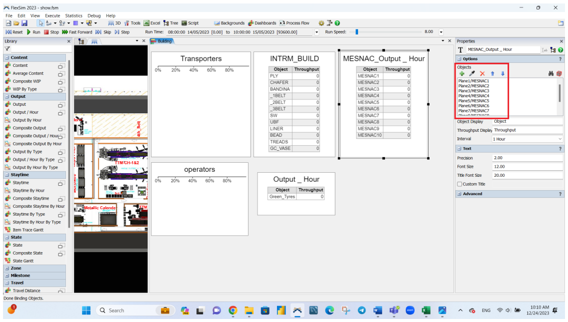


Figure 5.2. Attaching the MESNAC machines to the Output Dashboard

5.2 Results and Discussions

The inception and intricate modeling of the manufacturing facility within the FlexSim software framework stand as formidable accomplishments, entailing an extended temporal investment for its realization. Nevertheless, it is imperative to underscore that the mere creation and simulation of the factory within the FlexSim environment constitute a foundational step but are inherently insufficient. The scholarly merit of the thesis is contingent upon the comprehensive explication and dissemination of the ensuing results and consequential insights derived from this endeavor. Therefore, in the pursuit of academic rigor and the enrichment of knowledge in the field, I am compelled to report the following results:

I. Assumptions for Results 1 and 2:
Input Materials
Average Material Requirement Based
Transportation Losses
No Head Count Losses
Predefined Safety Stock
No Scrap Losses

II. Assumptions for results 3 and 4:
Infinite Input Materials
No transportation losses
No Head Count Losses
No Predefined Safety Stock
No scrap Losses

III. General Assumptions for all Results:

Handling Equipment Quantity

SF MATERIAL BOBBINS	QUANTITY
PLY	57
CHAFER	533
BELT1	
BELT2	
BELT3	
UBF	433
SIDEWALL	
BEAD	92
LINER	55
BANDINA	78
TREAD	121

Handling Equipment Tires Capacity
(Tires/Bobbins)

SF MATERIAL	CAPACITY
PLY	97
CHAFER	20
BELT1	46
BELT2	46
BELT3	81
UBF	19
LINER	98
BEAD	25
SIDEWALL	29
BANDINA	139
TREAD	44

Figure 5.3. Industrial Engineering Assumptions

1. **Plant Layout**

   In order to get the optimal directions of the transporters, I hide the 3D model because it is very heavy and run it for 86400 seconds, then I can show the model and take a screenshot of the layout. I did this tenth of times to get the optimal layout, and each time I change the directions, the results are changing too.
   I had used the heat map in the A star navigator in order to track the most used ways by the transporters to see what corridors needed to be two ways or one way.
   You can see in Fig.5.4 that there are more condensations of blue color indicator on the parameter or border corridors, which indicates that the usage of these ways by the transporters is very high, and it is recommended to make these ways double-way corridors.
   On the contrary, if you look at the red rectangles, we can see that the middle corridor of the layout, or the one below the PLY machines, is either not used at all or just used a few times.

2. **Optimal Number of Transporters**

   As a result of managing the process flow and creating the proper barriers according to the given layout by the architecture engineering team, the number of transporters used has been reduced from 12 transporters (see Fig.4.19) to 7 transporters (6 for semi-finishing and 1 for building).

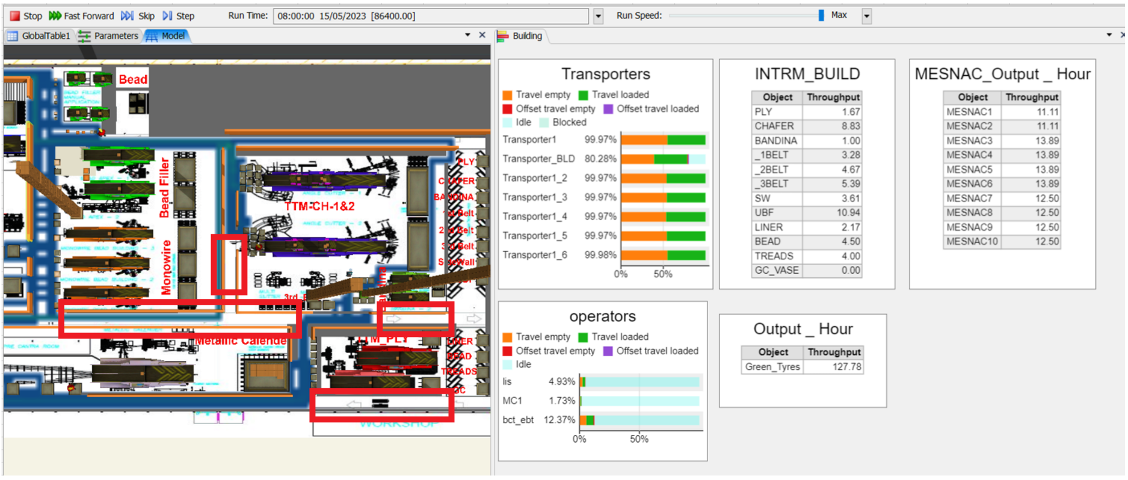


Figure 5.4. Bi-Directional Corridors

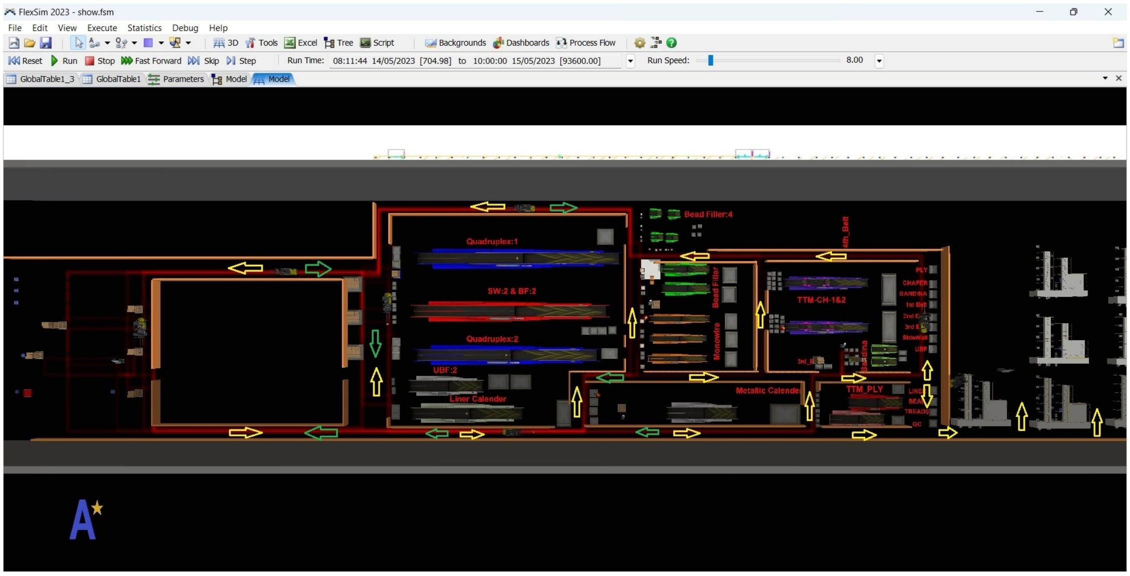


Figure 5.5. Bi-Directional Plant Layout

To prove that these ways are recommended to be eliminated and exploited for other things that can effect the KPIs, like adding one machine or creating a storage area for semi-finishing outputs that are used again by semi-finishing machines, I closed the middle corridor completely, and the simulation gave me these results.

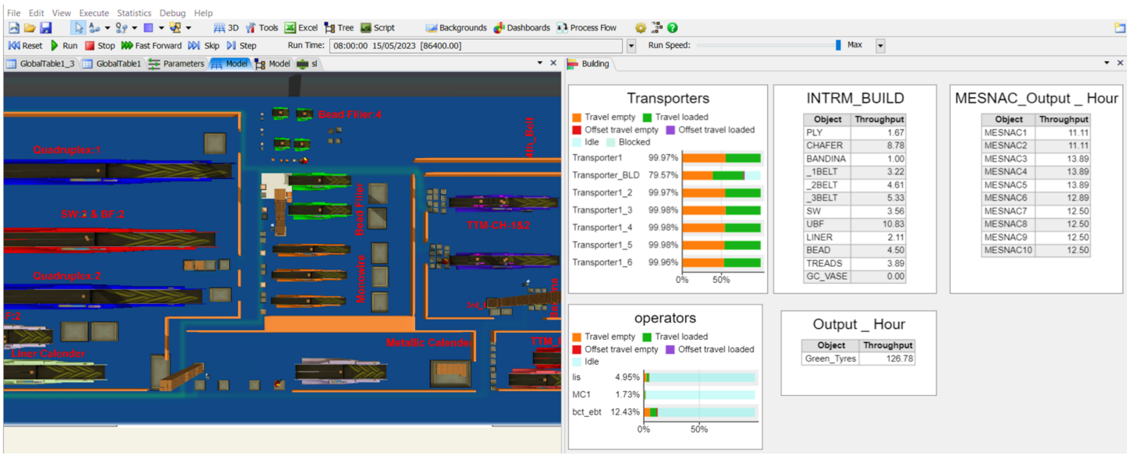


Figure 5.6. Elimination of the Middle Corridor

In a unidirectional flow, the transporters can travel in one direction, so they enter from one side and exist from another side. You can follow the yellow arrows, which indicate the optimal direction that the transporter must take to deliver the requirements (see Fig. 5.8).
As expected, the output of the green tires will decrease because I have added more restrictions to the transporters.

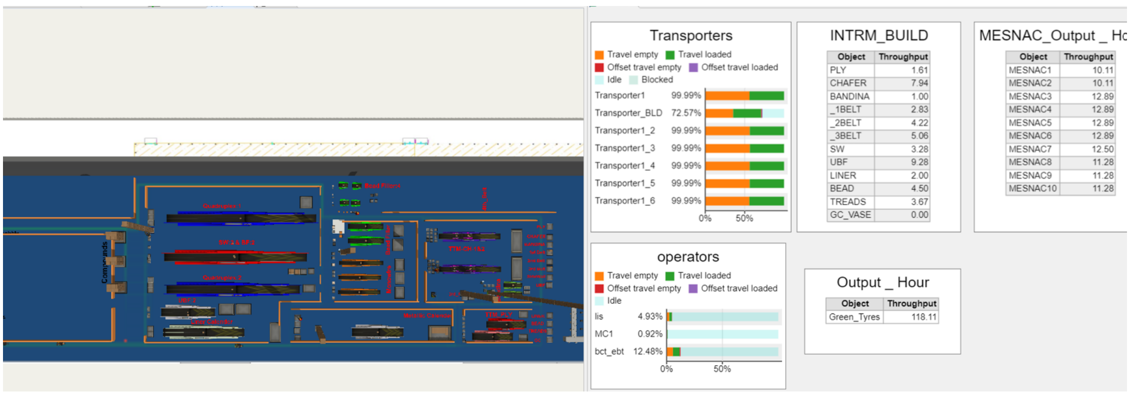


Figure 5.7. Uni-Directional Corridors

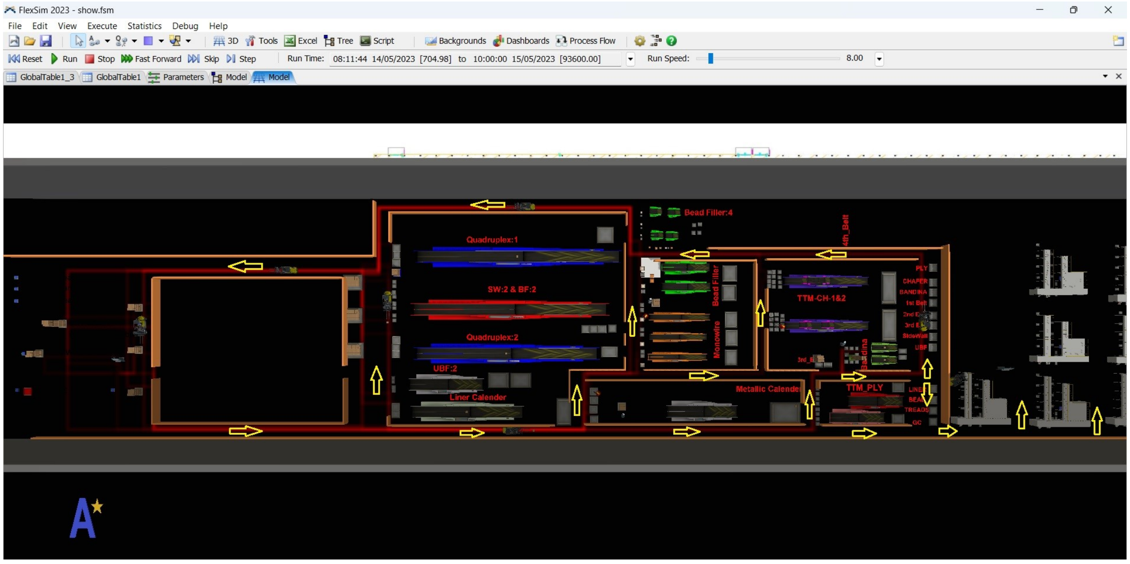


Figure 5.8. Uni-Directional Plant Layout

3. **WIP Evaluation and Effects on Production System: Simulation for 100 days**
   The output of the semi-finishing machines collected in the queues is called intermediate storage before being sent to the building area, which includes 10 MESNAC machines that are responsible for assembling these materials to produce the green tires. You can see these queues surrounded by a yellow rectangle in the following Fig. 5.9.

Figure 5.9. Intermediate Queues

In the following results, the **minimum WIP required** is calculated by averaging the content of 100 days, and the **intermediate WIP** represents all the output sent to the building area after 100 days. Each intermediate queue is connected to ten input queues for 10 different MESNAC machines. These results shows that we need initial stock

Minimum_WIP_Required

Object	Throughput
liner_inter	3871
bandina_inter	2799
chafer_inter	18516
sw_inter	13395
treads_inter	8410
bfa_inter	14766
belt1_inrer	8411
belt2_inter	8234
belt3_inter	4694
ply_inter	3830
ubf_inter	19488

Intermediate_WIP

Object	Bobbins
liner_inter	5210.38
bandina_inter	313.46
chafer_inter	37927.44
sw_inter	4200.98
treads_inter	4474.88
bfa_inter	0.00
belt1_inrer	28836.26
belt2_inter	36532.17
belt3_inter	20747.54
ply_inter	2108.25
ubf_inter	8454.69

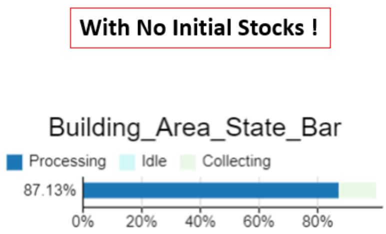


Figure 5.10. No Initial Stocks

The results in Fig.5.9 show that when we start running the factory, we definitely need initial stocks since the saturation (OEE) of the MESNAC machine is 87 percent compared to the control results shown in Fig.5.11.

Minimum_WIP_Required

Object	Throughput
liner_inter	4330
bandina_inter	3157
chafer_inter	21176
sw_inter	15173
treads_inter	9628
bfa_inter	16940
belt1_inrer	9370
belt2_inter	9210
belt3_inter	5228
ply_inter	4366
ubf_inter	22292

Intermediate_WIP

Object	Bobbins
liner_inter	5038.85
bandina_inter	146.64
chafer_inter	37328.15
sw_inter	3368.96
treads_inter	3947.16
bfa_inter	100000.00
belt1_inrer	28827.71
belt2_inter	36675.92
belt3_inter	20829.51
ply_inter	1870.68
ubf_inter	7194.54

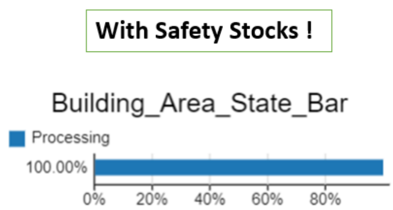


Figure 5.11. With Initial Stocks

When I placed sources to supply initial stocks in the intermediate queues and started running the model for 100 days, the saturation of the MESNAC machines reached 100 percent, and the needed stocks per day were simply calculated by dividing each number by 100.

Anticipated outcomes have materialized, revealing a noteworthy advancement in Overall Equipment Efficiency (OEE) by 13 percent. This consequential augmentation has, in turn, wielded a palpable influence, effectuating a discernible surge in the production of green tires. Specifically, the production output has escalated from 369 units per day to 424 units per day under optimal conditions. This observed correlation underscores the critical significance of maximizing OEE for MESNAC machines. In light of these findings, a strategic imperative emerges, necessitating the judicious placement of initial stocks within the operational queues of these machines. This strategic alignment not only acknowledges the imperative role of OEE enhancement but also posits the optimization of initial stock placement as a key determinant for achieving and sustaining peak operational performance within the MESNAC manufacturing framework. As such, the results proffer valuable insights into the intricacies of production efficiency, laying the foundation for strategic decision-making and operational enhancements within the context of advanced manufacturing systems.

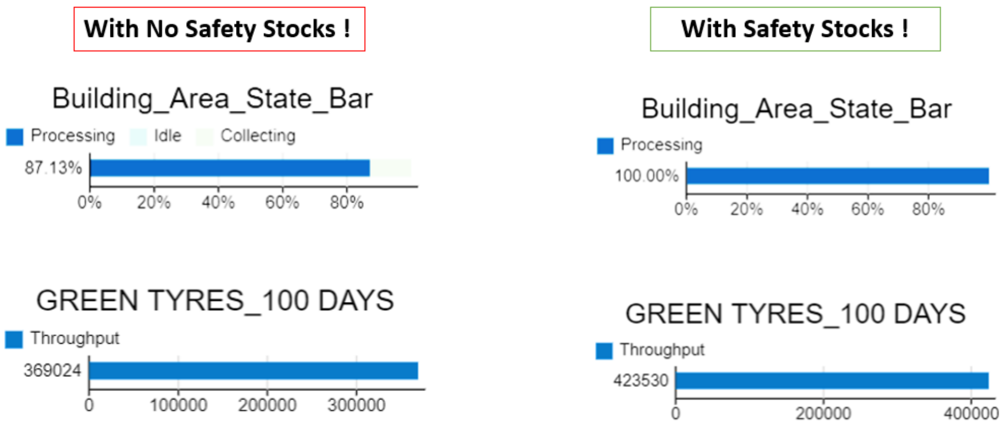


Figure 5.12. Comparative Results

4. **Individual OEE Evaluation and Effects on Production System: Simulation for 100 days**

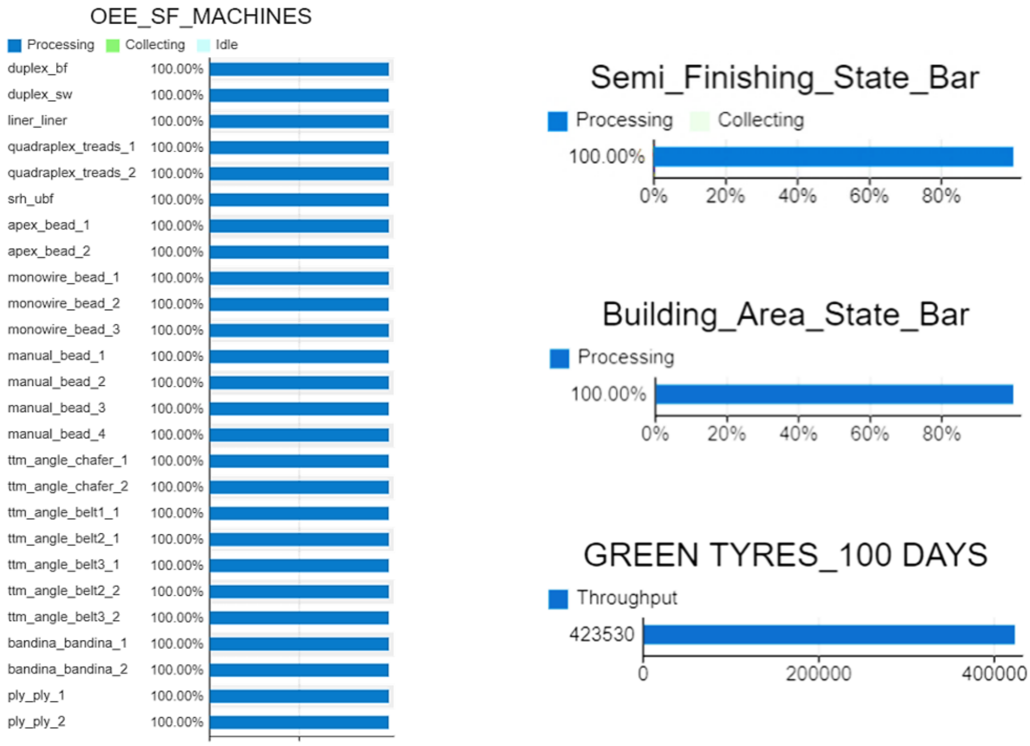


Figure 5.13. Ideal Case With Initial Stocks-Control Experiment

The Overall Equipment Efficiency (OEE) of the semi-finishing process attains a remarkable pinnacle, registering at an optimal 100 percent across all machines. This notable achievement is underpinned by a meticulous mitigation strategy employed to obviate any potential losses. Specifically, judicious implementation of A-connections has been instrumental in the seamless transfer of materials, strategically mitigating losses that might otherwise be incurred in the production continuum. Additionally, an innovative approach involves the establishment of infinite material sources within the warehouse area, strategically designed to circumvent losses and ensure an unimpeded material supply chain.

It is imperative to underscore that this deliberate circumvention of losses serves a dual purpose. Firstly, it facilitates an accurate evaluation of real-world operational efficiency by eliminating confounding factors that could arise from avoidable losses. Secondly, it sets the stage for a rigorous comparative analysis, allowing for a direct comparison between the actual results and those derived from controlled experiments or idle scenarios. This methodical approach underscores the commitment to precision and reliability in assessing the efficacy of the semi-finishing process, contributing to the validity and robustness of the experimental outcomes (see Fig. 5.13).

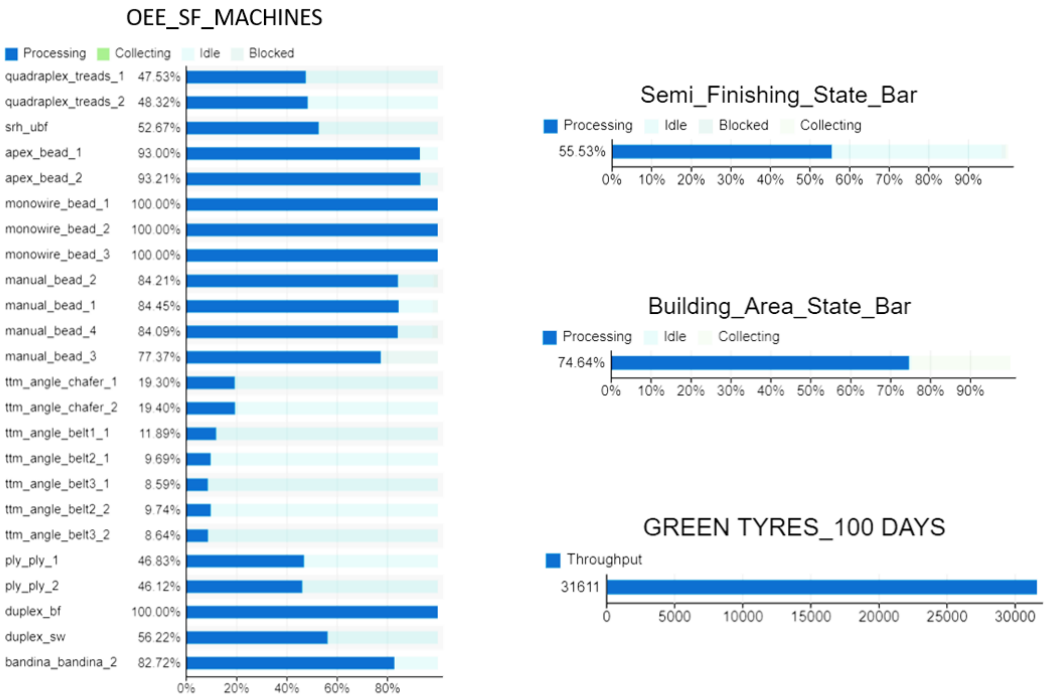


Figure 5.14. Real Case

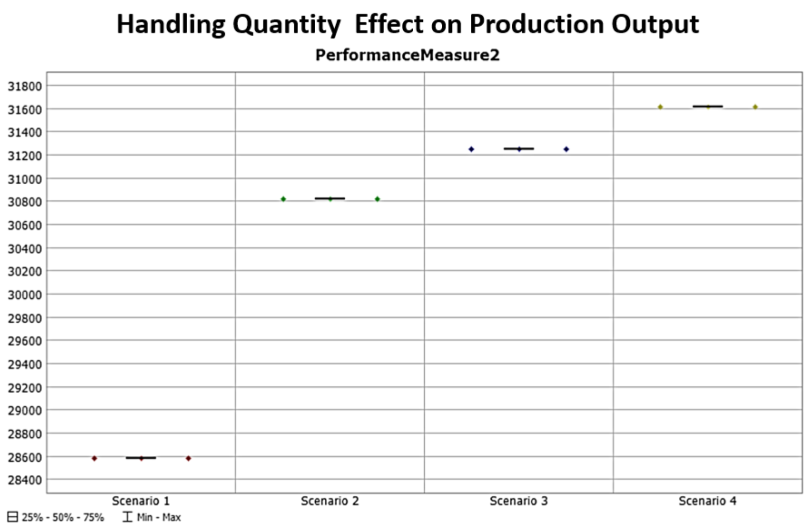
The results shown in Fig. 5.14 represents the real situation, taking into consideration the transportation losses and rotation of the handling equipment, and this is a very important point to discuss because, as you can see in the results in Fig. 5.7 and Fig. 5.6, the transporters travel empty half of the distance because, logically speaking, the transporter needs to travel for loading the same distance to travel for unloading, but in reality when he travel back to load , he will take the empty handling equipment again to the loading station, because as shown in the table of the assumption in Fig. 5.3 there are a limited quantity of the handling equipment which are always rotating in a loop withing the machines depending on their needs.

You can see some strange results in Fig. 5.14 regarding the OEE in the semi-finishing area, one in the Bead production line and the other in the Belts production line. Regarding the Bead this is happening because the cycle time of the Bead Filler Applicator machines is about 4 times that of the monowire bead and the quadruplex machines, which supply the Bead Filler machines, so there will be no waiting for the materials. Taking that into consideration, I assumed there are no

head count losses or machine losses, which makes their OEEs equal to 100 percent. On the contrary, Chafer 1, Belt 1, Belt 2, and Belt 3, are in fact one machine, which means that we should add their OEEs, which is equal to 78 percent.
The semi-finishing stat bar represents the overall OEE or composite state, for all machines , as well as the building area state bar. The final output of the green tires is about 316/2 = 150 tires.

5. **Effect of Handling Equipment Quantity on the Production System:**

   To test the effect of the Handling Equipment Quantity on the production, I took a Bead Filler as an example. To run the experimental analysis, I chose 4 different numbers, and it was obvious that the production increased as the handling equipment increased, but it is noteworthy to mention that this affect has a limit, and the relation is not directly proportional but more exponential. This is happening because if there is a lot of handling equipment, there will be confusion with the priorities of the transporters because there will also be an unwanted accumulation.



	Emtpy_BF_Truck
Scenario 1	30
Scenario 2	50
Scenario 3	80
Scenario 4	112

Figure 5.15. Handling Equipment Quantity Experimental Results

Within the realm of my comprehensive testing procedures, a meticulous exploration was conducted to gauge the impact of varying handling equipment capacity and bobbin sizes on the tire production process. This involved a thorough investigation without altering the numerical count of these elements. The results unearthed a discernible and directly proportional relationship between the length of the bobbin and the ensuing tire production(see Fig.5.16). To elaborate, an augmentation in bobbin length exhibited a corresponding increase in the manufacturing output of tires. It is imperative to acknowledge, however, that this correlation possesses certain constraints; there is a definitive limitation on the achievable length. Unfortunately, a thorough examination of this limitation was beyond the scope of my current study. Delving into such intricacies necessitates a more profound analysis that encompasses detailed scrutiny of available dimensions and numerous other facets. This complexity calls for an in-depth investigation, a task that remains pending as it requires close collaboration with the company for the definition of specifications. Future studies, extending beyond the present scope, might delve into this nuanced limitation to unveil a more comprehensive understanding of the interplay between bobbin length and tire production, subsequently refining the model for even more precise operational insights.

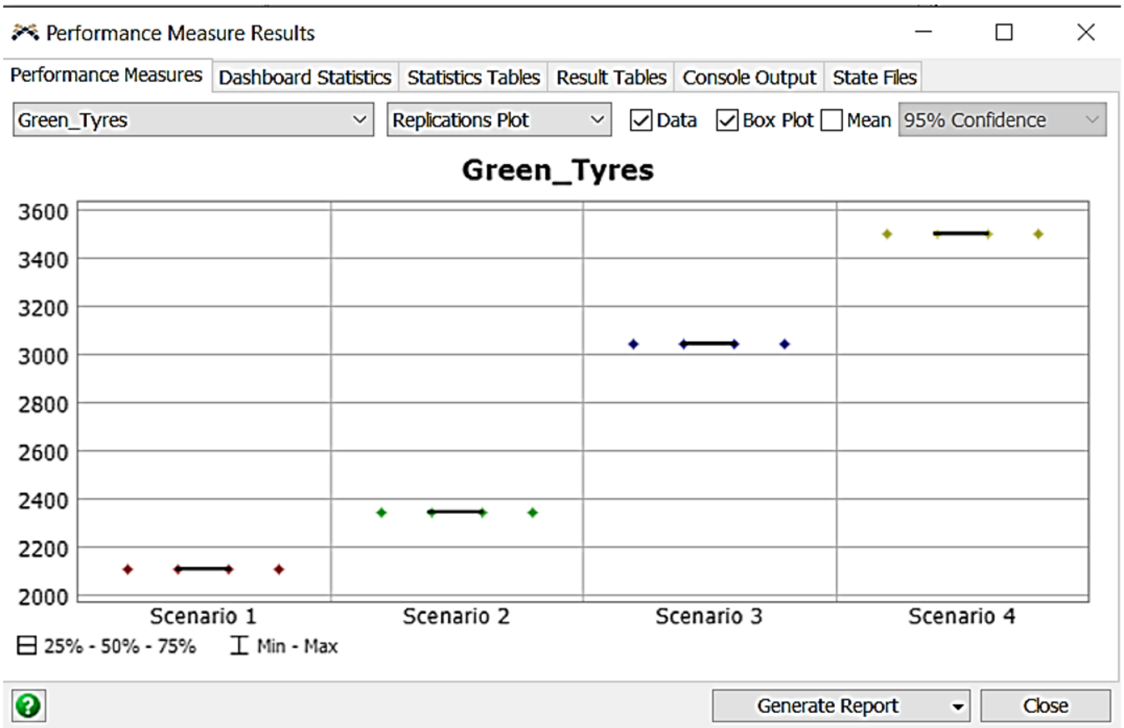


Figure 5.16. Bobbin Length Experimental Results

- ## Summary for the Results

In this section, I have succinctly summarized the findings presented in the three tables to enhance clarity. Given the abundance of details and information, the aim is to provide a more streamlined and comprehensible overview.

Available Scenarios	Composite Semi_Finishin OEE	Composite Building OEE	Green_Tyres/day
Idle Case	100%	100%	4235
Maximum Feasible Case	75%	100%	3690
Real Case_ Rotation of Heq.	60%	100%	3016
Real Case_ Transportation_SF	60%	78%	2856

Figure 5.17. Summary of Composite OEE

I have developed four scenarios for analysis. The first scenario, labeled as idle case one, assumes zero losses. The term "composite OEE" refers to the overall OEE encompassing all machines in the specified area. The second scenario explores the maximum feasible or possible situation under the condition of a direct connection, where materials are consistently available and the only losses are related to machine cycle times. In the third scenario, mirroring the second, semi-finishing machines are considered to wait for handling equipment returning from the building area. The fourth scenario takes into account transportation losses, along with the rotation of handling equipment and uni-directional movements. This involves transporters moving in one direction in each corridor, unable to deliver materials, and returning through the same path.

Available Scenarios	Green Tyres/hour	Green Tyres/day
One Way	119	2856
Tow Ways (middle_coridor)	128	3072
Two Ways (no middle_coridor)	127	3043

Figure 5.18. Summary of Transportation Analysis

Within the above table, I have encapsulated three transportation scenarios. The initial scenario involves a one-way system where transporters enter from one side and exit from another, as depicted in the results showcased in Fig. 5.8. In this configuration, the factory is capable of producing 2856 tires daily. The second scenario features a bi-directional approach, where all corridors permit movement in two directions, as illustrated in Fig. 5.5. In this setup, the factory's production capacity increases to 3072 tires per day, as evidenced in Fig.5.6. The last scenario demonstrates the model's flexibility by eliminating the middle corridor. This adjustment allows the company to assess the impact of such layout changes on daily tire production, providing valuable insights even if the layout is altered in the future.

Semi_Finishing Product	TOTAL HANDLING EQUIPMENTS	Handling Equipment Capacity (Tyres)	WIP (quantity)	WIP(days)	I.E. WIP(days)	Minimum INTRM Output Required
LINER	55	98	45	1.47	1.30	44
BANDINA	78	139	34	1.58	1.30	31
CHAFER	57	20	242	1.61	1.30	213
BELT1	110	46	100	1.53	1.30	93
BELT2	110	46	100	1.53	1.30	93
BELT3	62	81	52	1.40	1.30	54
PLY	57	97	47	1.52	1.30	44
UBF	262	19	252	1.60	1.30	224
TREADS	121	44	111	1.63	1.30	97
SW	171	29	161	1.56	1.30	148

Figure 5.19. Summary of the Result for the Chosen Scenario: Real Case

Within the above table, I have consolidated information pertaining to the Work In Process (WIP) for intermediate queues and the capacity of the bobbins for each material in the selected scenario. This scenario is delineated in the last table of Fig. 5.17 and the first one in Fig. 5.18, with a daily tire production capacity of 2856. The "WIP in terms of days" column denotes the duration these materials can reside in the queues. Additionally, the Industrial Engineering team's calculations (I.E.) closely align with the results obtained from FlexSim.

5.3 Usage of the Model

The implementation of an advanced simulation model holds immense promise for Prometeon Tyre Group as they embark on the establishment of a new factory. Developed using FlexSim software, this model offers a multifaceted approach, optimizing machine layout, streamlining processes, and providing adaptability for future changes. Its benefits encompass enhanced operational efficiency, cost reduction, and sustainability, positioning it as a pivotal tool for informed decision-making in the company's pursuit of manufacturing excellence.

1. **Operational Efficiency**

   a. Optimized Layout Design:
   The 3D model meticulously represents the entire production line, orchestrating an optimized layout that seamlessly guides material flow from the warehouse through the semifinishing area to the building area. This spatial intelligence enhances operational efficiency by minimizing unnecessary movements and optimizing the utilization of available space.

   b. Resource Allocation:
   The model's parameterized architecture proves instrumental in resource allocation. It empowers the company to dynamically adjust the number of machines and transporters, ensuring optimal resource distribution. This adaptability ensures operational agility, and future studies could explore real-time data integration to dynamically adjust resources based on live production data, thereby optimizing efficiency even more effectively.

2. **Cost Reduction and Profitability**

a. Cost Analysis:
The model's innate flexibility allows for swift and effective cost analysis. The ability to adjust parameters, such as the number of machines and transporters, provides the company with a versatile tool to simulate and analyze cost scenarios. This adaptability promotes a proactive approach to cost management, enhancing overall profitability.

b. Return on Investment (ROI):
Through dynamic parameter adjustments, the model facilitates a nuanced analysis of Return on Investment (ROI). Simulating various scenarios enables the company to gauge financial outcomes under different production configurations, informing strategic decisions that maximize profitability. Future analyses could explore more intricate financial models, incorporating variables like market fluctuations and inflation rates for a more comprehensive understanding of ROI under diverse economic conditions.

3. **Environmental Sustainability**

   a. Energy Efficiency:
   While not explicitly stated, the model inherently contributes to energy efficiency. The streamlined material flow and adaptable nature of the model allow for optimal machine usage and reduced idle times, indirectly minimizing energy consumption.

   b. Waste Reduction:
   Although not explicitly mentioned, the model's optimization of material flow likely contributes to waste reduction. Future studies could focus on explicit waste reduction strategies, integrating real-time data for more precise waste minimization.

4. **Risk Mitigation**

   a. Scenario Analysis:
   The model's parameterization supports robust scenario analysis. By simulating changes in the production line, such as alterations in machine numbers, the company gains valuable insights for risk mitigation. Identifying potential challenges and adapting the model accordingly ensures resilience against unforeseen circumstances. Future studies might explore more advanced predictive analytics within the model to anticipate and proactively address potential supply chain disruptions.

   b. Supply Chain Resilience:
   The model's flexibility inherently contributes to enhanced supply chain resilience. The capacity to adjust parameters enables the company to assess and adapt the production line promptly, ensuring continuous operational efficiency even in the face of supply chain disruptions.

5. **Scalability and Flexibility**

   a. Scalability Planning:
   The model's dynamic parameterization proves pivotal in planning for scalability. The ease with which the company can adjust the number of machines and transporters allows for efficient planning to accommodate future growth and changing production demands. Future studies may explore predictive modeling techniques to anticipate market changes and automatically adjust production parameters in real-time, further enhancing adaptability.

   b. Adaptability to Market Changes:
   The parameterization feature ensures the model's adaptability to market changes. Swift adjustments in machine numbers and transporters enable the company to respond effectively to shifts in market demand, maintaining competitiveness and operational excellence.

   By intricately exploring these aspects and seamlessly integrating future study considerations, your model emerges as a sophisticated tool for Prometeon Tyre Group, optimizing current operations and laying the groundwork for future adaptability and growth.

Chapter 6

Conclusion

In the preceding chapters, I meticulously introduced the operational challenges faced by Prometeon Tyre Group's tire factories, specifically honing in on the critical need for heightened flexibility and efficiency within their manufacturing processes. The crux of this thesis lay in proposing a viable solution to this predicament, utilizing Discrete Event Simulation as the foundational framework. The robustness of this approach was substantiated by an extensive examination of case studies from analogous industrial contexts, laying the groundwork for a comprehensive and effective resolution.

The utilization of Discrete Event Simulation, coupled with a comprehensive review of case studies, not only provided a theoretical framework but also validated its practical efficacy. The identification of optimal forklift transporter numbers, their strategic placement, and the subsequent production increase underscore the immediate applicability of the proposed solution. Furthermore, the detailed insights into the Minimum Work in Progress (WIP) and the requisite number of bobbins for each material present a blueprint for effective resource allocation and inventory management.

The dynamic relationships highlighted in Figures 5.3 and 5.16, showcasing the impact of handling equipment quantity and bobbin capacity on green tire production, respectively, offer strategic guidance for operational planning. However, it is imperative to recognize that these findings, while robust and illuminating, form part of a larger puzzle.

As we look towards the future, the proposed next steps—comprising a granular analysis of each machine, considerations of head count and machine-specific losses, and a foray into financial discussions—represent a natural progression. These steps will not only enrich the understanding of the operational intricacies within the tire manufacturing process but will also elevate the discourse to a more holistic level.

One must acknowledge that the current study, like any scientific endeavor, has its limitations. The focus on the warehouse-to-building process, while essential, omits a more exhaustive exploration of the broader manufacturing environment. Future research endeavors should broaden the scope to encompass a comprehensive analysis of each machine, taking into account the nuanced factors influencing head count losses and machine-specific inefficiencies.

Moreover, the discussion of financial implications offers a critical perspective on the economic viability of the proposed solutions. This involves not only understanding the immediate costs and benefits but also projecting the long-term financial impact of the suggested changes.

In conclusion, this thesis lays a solid foundation for future research endeavors. It has successfully addressed the identified problem, providing actionable solutions and insights. However, the journey is far from complete. The detailed analyses, strategic recommendations, and dynamic relationships uncovered in this study pave the way for a more profound exploration into the complexities of tire manufacturing. The limitations identified herein serve as guideposts for future investigations, urging a comprehensive and holistic understanding of the operational challenges and opportunities within the industry.

Bibliography

[1] Nicoleta Chicu, Adina-Liliana Prioteasa, and Alecxandrina Deaconu. Current trends and perspectives in tyre industry. *Studia Universitatis Vasile Goldiș Arad, Seria Științe Economice*, 30(2):36–56, 2020.

[2] Marina Paradiso. E-commerce and digital marketing in china pirelli case study. 2017.

[3] Stewart Robinson. Discrete-event simulation: from the pioneers to the present, what next? *Journal of the Operational Research Society*, 56:619–629, 2005.

[4] B. Demir and M. Erdoğan. The hardenability of austenite with different alloy content and dispersion in dual-phase steels. *Journal of Materials Processing Technology*, 208(1-3):75–84, November 2008.

[5] Onur Özgün and Yaman Barlas. Discrete vs. continuous simulation: When does it matter. 6:1–22, 2009.

[6] William B Nordgren. Flexsim simulation environment. 1:250–252, 2002.

[7] Nordgren. Flexsim simulation environment. 1:197–200, 2003.

[8] Jonas F Leon, Paolo Marone, Mohammad Peyman, Yuda Li, Laura Calvet, Mohammad Dehghanimohammadabadi, and Angel A Juan. A tutorial on combining flexsim with python for developing discrete-event simheuristics. pages 1386–1400, 2022.

[9] James Byrne, Cathal Heavey, and Peter J Byrne. A review of web-based simulation and supporting tools. *Simulation modelling practice and theory*, 18(3):253–276, 2010.

[10] Tai-Jung Chen, Yu-Ching Lee, and Chin-Hsin Chiang. Optimizing production layout and capacity via flexsim–a case study of y factory. 847(1):012029, 2020.

[11] Bill Nordgren. Introduction to simulation with flexsim. pages 4242–4242, 2018.

[12] N Muhammad and C Jeng Feng. Methodology to optimize value in discrete event imulation for production planning and control studies. pages 676–684, 2014.

[13] Sándor FORRAI, Balázs LUDANYI, István Péter SZABÓ, Justyna SMAGOWICZ, and Cezary SZWED. With the use of 3d simulation modeling.

[14] Ikpe Justice Akpan and Murali Shanker. A comparative evaluation of the effectiveness of virtual reality, 3d visualization and 2d visual interactive simulation: an exploratory meta-analysis. *Simulation*, 95(2):145–170, 2019.

[15] YR Wang and AN Chen. Production logistics simulation and optimization of industrial enterprise based on flexsim. *International Journal of Simulation Modelling*, 15(4):732–741, 2016.

[16] Evgeniy Lavrov, Yana Chybiriak, Olga Siryk, Victoriya Logvinenko, and Anna Zakharova. Training of specialists for adaptive management. techniques for teaching

computer analysis of automated production systems in the flexsim environment. pages 106–118, 2021.

[17] Pawel Pawlewski, Karolina Rejmicz, Kamil Stasiak, and Michał Pieprz. Just in sequence delivery improvement based on flexsim simulation experiment. pages 1–12, 2012.

[18] B Santhosh Kumar, V Mahesh, and B Satish Kumar. Modeling and analysis of flexible manufacturing system with flexsim. *International Journal of Computational Engineering Research*, 5(10):1–6, 2015.

[19] Aulia Ishak, Ahmad Faiz Zubair, and Assilla Sekar Cendani. Production line simulation in vise using the flexsim application. 1003(1):012103, 2020.

[20] Aurellia Kharisty Tjusila, Lina Gozali, and Carla Olyvia Doaly. Factory re-layout with slp, craft, corelap, promodel, and flexsim for optimization of material flow movement. *no. March*, pages 531–543, 2022.

[21] Jose Arturo Garza-Reyes, Steve Eldridge, Kevin D Barber, and Horacio Soriano-Meier. Overall equipment effectiveness (oee) and process capability (pc) measures: A relationship analysis. *International Journal of Quality & Reliability Management*, 27(1):48–62, 2010.

[22] Jose Arturo Garza-Reyes. From measuring overall equipment effectiveness (oee) to overall resource effectiveness (ore). *Journal of Quality in Maintenance Engineering*, 21(4):506–527, 2015.

[23] Lauren Van De Ginste, El-Houssaine Aghezzaf, and Johannes Cottyn. The role of equipment flexibility in overall equipment effectiveness (oee)-driven process improvement. *Procedia CIRP*, 107:289–294, 2022.

[24] Ainul Akmar Mokhtar Ruwaida Aliyu. Research advances in the application of flexsim: A perspective on machine reliability, availability, and maintainability optimization. *Journal of Hunan University Natural Sciences*, 48(9), 2021.

[25] Aulia Ishak, Ahmad Faiz Zubair, and Assilla Sekar Cendani. Production line simulation in vise using the flexsim application. 1003(1):012103, 2020.

[26] Liu Yafei, Wang Qingming, and Ge Peng. Research on simulation and optimization of warehouse logistics based on flexsim-take c company as an example. pages 288–293, 2018.

[27] R Sundar, AN Balaji, and RM Satheesh Kumar. A review on lean manufacturing implementation techniques. *Procedia Engineering*, 97:1875–1885, 2014.

[28] Christian Thies, Karsten Kieckhäfer, Thomas S Spengler, and Manbir S Sodhi. Operations research for sustainability assessment of products: A review. *European Journal of Operational Research*, 274(1):1–21, 2019.

[29] Fara Kamila Hudy, Nidaru Ainul Fikri, and Udisubakti Ciptomulyono. Integrated model of lean and risk mitigation for sustainability performance measurement in the lubricants manufacturing industry. *The Eurasia Proceedings of Science Technology Engineering and Mathematics*, 23:452–463, 2023.

[30] John Smith and Mary Johnson. Optimizing inventory management in a tire warehouse using flexsim. *Logistics and Supply Chain Management Journal*, 15(3):45–62, 2020.

[31] John Smith and Mary Johnson. Optimizing quality control in tire manufacturing:

A flexsim case study. *Manufacturing Engineering Journal*, 25(4):67–82, 2021.

[32] David Brown and Susan Davis. Optimizing material handling in tire distribution: A flexsim approach. *Logistics and Supply Chain Management Journal*, 18(2):34–47, 2020.

[33] Robert Williams and Laura Turner. Optimizing resource allocation in a tire factory: A flexsim study. *Operations Management Journal*, 22(3):56–69, 2019.